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THE CATTLE OF INDIA AND THEIR DEVELOPMENT

F. WARE

(*Animal Husbandry Commissioner with Government of India*)

WITH PLATES 1—6

Introduction.—When making a public presentation of two stud bulls for the improvement of cattle in Delhi Province, H.E. the Marquess of Linlithgow, the Viceroy of India and previously Chairman of the Royal Commission on Agriculture in India, observed that 'the cow and the working bullock bear on their patient backs the whole structure of Indian agriculture'. This remark puts in a nutshell the great importance of cattle to Indian economy. India is a vast agricultural country with a human population of 350 million people, 90 per cent. of whom live on agriculture. The bullock is almost the only source of power available for carrying out the various agricultural operations extending over an area of about 300 million acres of cultivation, besides acting as the major road-transport animal. Most of the peoples are vegetarian and depend entirely on milk and milk products as the source of animal protein in their diets. The social and economic importance of cattle to India is therefore self-evident.

The actual as well as the potential value of India's cattle industry is huge even in its present undeveloped state. The annual value of milk and milk products is by a conservative estimate not less than Rs. 300 crores (£225 million). The output of hides and skins, of which India is the largest exporter in the British Empire, is annually worth about Rs. 40 crores. Cattle labour is variously estimated to be worth between Rs. 300 and Rs. 500 crores annually, whilst the cash value of their manure, which may be used either for increasing soil fertility or as fuel, is about Rs. 270 crores.

With such an enormous potential value, the question of developing this industry has naturally received attention, and a reference to the background of the problem may enable the reader to appreciate the difficulties in the way of rapid large-scale improvements in India.

First, the number of cattle in India is far too great for the fodder resources of the country. The area of cultivated land available per head of bovine population is 1·8 acres, as compared with 3·4 acres in Great Britain, 4·5 in New Zealand, 31·4 in Canada, and 24·9 in U.S.A. The Royal Commission on Agriculture estimated that for every 100 acres of net sown area there are 21 acres fallow, 92 acres of grazing, and 20 bullocks, 17 cows, 16 other cattle, 3 male buffaloes, 3 female buffaloes, 5 young buffaloes, and 27 sheep and goats. This shows the pressure on the land and the acute nature of the fodder problem. Over wide areas concentrates are fed only to transport ponies and bullocks and to milch buffaloes, the remainder of the live stock of a village having to depend on what roughage they can pick up. The grazing land is very poor after the monsoon, i.e. for most of the year, and in many localities is then little more than an exercise ground. In the cold season animals graze on the

crop stubbles, and may receive a supplement of straw or hay, but during the hot weather until the break of the rainy season the supply of fodder gradually diminishes and the feeding of stock becomes very difficult.

Secondly, cattle breeding is mostly in the hands of small farmers who are poor and illiterate. According to the *Report on a Village Enquiry* [1], which records the results of an intensive survey in selected breeding tracts, the average size of holdings in different parts of the country varies between 7 and 23 acres. These small areas have to support 6–9 persons and 3–7 head of cattle each. Such small farmers are naturally unable to invest capital in pedigree stud animals, and there has been a tendency to rely on quantity rather than quality, as an insurance against such cattle plagues as rinderpest and haemorrhagic septicaemia, which have visited the country periodically in the past and carried off large numbers of animals.

Thirdly, the cow is a sacred animal to the Hindu. According to the Vedas, she should not be slaughtered, but allowed to live after her economic period is over and die a natural death.

In many parts of India these different factors are leading to a very serious situation. Not only is the result of overstocking seen in the shortage of food, but it is also one of the major causes of soil erosion, as Gorrie [2] wrote in 1937: 'In much of India the last vestiges of shrub growth already form the ordinary daily ration for the village herd. The amount of erosion caused directly through this state of affairs has to be seen to be believed.'

The recognized breeds of Indian cattle.—The foregoing paragraphs draw rather a sorry picture of the general state of cattle in India, and the impression gained by casual visitors to this country, who judge the position by the cattle they see from the train, is usually much the same. It appears also that little is generally known outside India regarding the different breeds that are included under the generic term of Indian Zebu or Brahman cattle, and it is, therefore, of interest to record that the latest attempt to enumerate these has resulted in the compilation of a list containing 28 breeds of cattle, covering a wide range of size, colour, and capability, in addition to 7 breeds of buffaloes.

It should be stated at once that there is a vast gulf between the capabilities of these animals and the ordinary village cattle, and it is proposed to show how these recognized breeds, which have already acquired a big reputation in tropical countries by reason of their drought-resisting qualities and ability to withstand attack by the major cattle plagues and tick-borne diseases, respond to better feeding and management, and what marked success has already been obtained in those breeds which have so far been selected for development.

Before doing this, however, something must be said of the physical characteristics of Indian cattle, as compared with other Zebus, and an attempt made to answer some of the questions raised by Curson and Thornton [3] in their study of the African Native Cattle. These authors suggest that the humped cattle of Africa may be provisionally classified into true Zebus (Asiatic in origin) and pseudo-Zebus (African in origin). The first class is again subdivided into lateral-horned and short-horned,

and these are described as possessing a long coffin-shaped skull with a convex profile and bifid thoracic superior spines. One of the divisions of the pseudo-Zebus is the lyre-horned, in which the skull is said to show marked evidence of Hamitic Longhorn influence, being wide in the forehead and the orbital arches prominent. The profile is generally flat. No osteological material of the lyre-horned Zebu has been examined, a point of interest to future investigators. Another suggested classification of the Zebus is by the position of the hump, which may be either cervico-thoracic and muscular or thoracic and musculo-fatty. If this classification is adopted, all present-day Indian cattle will fall into the latter class, with the exception of the Siri breed of Bhutan.

Following the arrangement of Olver [4], Indian cattle may be divided into five well-marked groups:

Group I. Lyre-horned grey cattle with wide forehead, prominent orbital arches, face flat or dished in profile, represented by the Kankrej, Malvi, and possibly Tharparkar, breeds.

Group II. Short-horned white or light-grey cattle, with a long coffin-shaped skull, orbital arches not prominent, face slightly convex in profile, represented by the Bhagnari, Nagori, Mehwati, Rath, Hariana, Krishna Valley, and Ongole breeds.

Group III. Ponderous, usually spotted red and white or brown and white, milch-type cattle with prominent forehead, pendulous dewlap and sheath, lateral and often curly horned, represented by the Gir, Sahiwal, Deoni, Nimari, and possibly Sindhi, breeds.

Group IV. Medium-sized compact draught-type animals, usually grey, with tight sheath, very prominent forehead, long pointed horns arising close together, represented by the Hallikar (Amrat Mahal), Khillari, Kangayam, Alumbadi, and Bargur breeds.

Group V. Small red or black cattle, often with white markings, short-horned, with tight sheath, poll and top of hump usually covered with coarse hairs, represented by the cattle of the Himalayan and Kumaon foot-hills, Lohani (Frontier Province), and Afghan breeds.

In addition there are a number of isolated breeds, such as the Dhanni of the North Punjab, Ponwar of the United Provinces, and Gaolao of the Central Provinces, which cannot be fitted into any of the above groups, and are probably of more recent origin.

This question of the origin of our domestic animals is always fascinating, and we are fortunate in India in being able to produce definite evidence that the same type of Zebu, which is found throughout the Indian sub-continent to-day, was in use as a domestic animal at the time of the ancient Indus-valley civilization represented by the ruined city of Mohan-jo-daro, which is estimated to date back to 3000 B.C.

L. H. Shirlaw [5] points out that there were actually two types of cattle in existence at the time of this civilization, 'a massive large-horned humped form and a smaller form with short horns which may possibly have been humpless'. It is also stated that the latter type is found only in the upper strata of the Mohan-jo-daro site, but there are abundant remains of humped bulls in every stratum. The author also quotes Sir John Marshall, who was in charge of the excavations at Mohan-jo-daro,

as saying that this large humped breed is closely allied to, if not identical with, the magnificent white and grey breed still common in Sind, Northern Gujrat, and Rajputana, i.e. the animals in Group I, all of which are renowned for their splendid draught qualities. Olver [4] has also drawn attention to the resemblance between the Kankrej breed, whose home is in Northern Gujrat, and the animal depicted on the seal which was recovered from the Mohan-jo-daro site (Plate 1, *c*), and even more striking is the resemblance between the animal on the seal, the lyre-horned Malvi breed of India, and the Peulhe or Gobra lyre-horned Zebu of West Africa, illustrated in the work of Curson and Thornton [3]. There is also a great likeness between the Kankrej breed and African Fulani cattle, as depicted by the same authors. It would thus appear that the lyre-horned cattle of India and Africa may have had a common origin, but if so it is difficult to accept the theory of Curson and Thornton that the lyre-horned Zebu represents an intermixture between the Hamitic Longhorn, a humpless animal, and the short-horned Zebu, a comparatively modern animal in Africa and, apparently, in India also.

According to Epstein [6], the short-horned Zebu is the result of interbreeding in India between *Bos brachyceros* and the lateral-horned Zebu. The only evidence that the former ever reached India is the possibly humpless variety recovered from the upper strata of the Indus valley, and no specimens of the lateral-horned Zebu have yet been found, unless one looks upon the milch breeds in Group III as having affinities with this type, which is represented in Africa by the Afrikander. In this connexion it is noteworthy that Bosman [7] states that an Afrikander cow off the veld will give as much as 30 lb. of milk a day. In any case we may accept the contention of Olver [4] that the short-horned Zebu, i.e. the animals in Group II, but not the animals in Group I, accompanied the Vedic Indo-Aryans during their invasions of India, which according to Smith [8] occurred between 2000 and 1500 B.C. Smith emphasizes the fact that these immigrants have stamped an indelible mark on the whole country from the Himalaya to Cape Comorin, and the same may be said of this group of cattle, which contains some of the best dual-purpose (milk and draught) breeds in India. Their penetration is very remarkable, and examples of the group now stretch diagonally across the subcontinent from Kalat, outside the North-West Frontier, to a point on the south-east coast a few miles north of Madras. Not only this, but the changes which have taken place during the southern migration have been very slight, and anyone who is not very familiar with these different breeds would probably consider the present-day arrangement largely artificial and find difficulty in separating one from the other, as for example the four specimens shown in Plate 2.

A reference has already been made to the possible origin of the animals in Group III, but this question awaits investigation before any pronouncement can be made. Suffice it to say that this group (Plate 3) is of very great economic importance to India, for included in it are those breeds which so far have shown the greatest potentiality as milk producers, as well as being suitable for crossing for beef purposes. The Gir, whose natural home is in the Gir forests of the Kathiawar peninsula on

the west coast of India, is usually looked upon as the oldest and indeed the basic breed of this group, and it is an interesting fact that from time to time animals showing the characteristic colouring of the Gir turn up in pedigree herds of allied breeds.

The essentially draught animals in Group IV are all found in the south of the peninsula, and may be said to be centred round the Hallikar breed of Mysore. The Amrat Mahal Department of that State has bred and developed these animals for many years past, and it was bullocks of this breed which received such high praise as transport animals from Sir Arthur Wellesley, afterwards Duke of Wellington, during his Indian campaigns. Nothing is known of the origin of the animals in this group (Plate 4), which are found covering a long but rather narrow plateau area from the Khillar tract in the south of the Bombay Presidency to the Bargur hills in the Madras Presidency. There is also an isolated collection of the Hallikar breed in Amrabad taluq in the south of Hyderabad State.

Lastly we come to the small animals of Group V, which are the most widely distributed throughout India. Examples of this group (Plate 5) are found scattered through all the villages of the plains, but they contain much mixed blood, and only in the more hilly tracts are they found in any state of purity. Possibly they were animals of this group that were found in the upper strata of the Mohan-jo-daro site, although it is suggested that the latter were humpless. These hill cattle, under ordinary conditions, show very little hump, but when well fed they develop into the typical musculo-fatty dorsal variety. They are very useful for ploughing work on the narrow terraces of the hill-sides on which they live, whilst in some of the breeds, e.g. Afghan and Lohani, the cows give as much as 12 lb. of milk a day.

Measures Adopted for Improvement

(*a*) *Activities of the Central Government.*—The Central Government maintains three research institutes for veterinary, agricultural, and dairy science, respectively. The Imperial Veterinary Research Institute, Mukteswar, which was founded in 1890, and is the first of these Central Research Institutes to celebrate its golden jubilee, was instructed 'to investigate diseases of domesticated animals in all provinces in India and to ascertain . . . by biological research . . . the means for preventing and curing such diseases'. As a result, this Institute, besides employing a strong body of research workers to investigate disease problems, has developed a large production side for the preparation of sera and vaccines and other biological products used in the diagnosis, prevention, and cure of pathological conditions affecting cattle and other animals in India. More recently an Animal Nutrition Section has been added to this Institute at Izatnagar, and problems relating to the nutrition of cattle and the relationship of nutrition and disease are now being investigated there.

The Central Dairy Research Institute, at present located at Bangalore, is investigating problems connected with dairying and the production of milk and milk products, both of the European and indigenous kind; it also provides courses of instruction for students desirous of taking up

dairying as a profession. Proposals are under consideration for the expansion of this Institute and its location in a more central part of India.

All these Central Institutes, including the Imperial Agricultural Research Institute, New Delhi, are maintaining pedigree herds of cattle which are being developed on scientific lines. This organization secures attention for the Gir, Sindhi, Hariana, Tharparkar, Sahiwal, and Kumaun Hill breeds of cattle, as well as the Murrah breed of buffaloes, and the success already obtained in some of these herds, details of which will be referred to later, is very marked.

The Government of India has also recently given tangible proof of its interest in cattle-breeding by providing a sum of money for inaugurating an All-India Cattle Show, such shows having been held at New Delhi in February of each year since 1938. An All-India Cattle Show Society has now been formed and it is hoped, with the help of contributions from the Provinces and States, to make this Show an annual and permanent event. The advantages of such a show, where cattle-breeders can meet once a year and discuss their numerous problems and compare results, need not be laboured; it also provides a unique opportunity for foreign buyers to see at a glance what India has to offer in the way of well-developed breeds suitable for export.

(*b*) *Imperial Council of Agricultural Research.*—The Imperial Council of Agricultural Research was established ten years ago at New Delhi as a direct consequence of the recommendations of the Royal Commission on Agriculture. The Council has given considerable impetus to cattle-breeding, and its efforts have resulted in much greater co-ordination and uniformity of effort. The Advisory Board of the Council is composed mainly of the Directors of Agriculture and Veterinary Services of the Provinces, and the meetings and discussions therein have enabled the Directors to exchange ideas and to shape their programmes and policies according to the requirements of the country as a whole. Collection and publication of data is one of the functions of the Council, and the publications issued so far on cattle-breeding and milk production have been very useful.

From its very inception the Council realized that the corner-stone of cattle improvement is pedigree registration. Accordingly, steps have been taken to define authoritatively the characteristics of the more important breeds of cattle, and a bulletin [9] has already been published containing the definitions of seven of the milch breeds of India. Details for the initiation of Central Herd-books for these breeds are under consideration and when they are settled herd-books will be opened and maintained by the Council. The scheme envisages a complete co-ordination of pedigree and performance by laying down that, in addition to conformation and descent, a prescribed minimum milk yield should be a condition of entry of cows in the herd-books.

Regular publication of such approved milk records as exist in dairy farms is now being made, and this activity will increase when the herd-books are in use. Studies of milk records are being made from time to time and the results published.

There is at present no arrangement for recording milk yields amongst

village cattle. Much propaganda is necessary in this direction and prejudices have frequently to be overcome. The Council has realized that non-official societies similar to those existing in other countries are essential, but they cannot be formed until the value and the advantages of milk recording have been demonstrated practically. A scheme has therefore been sanctioned for starting milk recording in the home of the breeds chosen for central registration. It is hoped that those owners whose animals are recorded under the scheme will eventually form themselves into milk-recording societies.

In the field of disease-control one of the most important contributions made by the Imperial Council of Agricultural Research is the appointment of Disease Investigation Officers in the various Provinces and States. The first batch was appointed in 1932, and a disease-investigation staff is now at work in every British province and in Hyderabad and Mysore States. When these officers were appointed it was emphasized that they should work in close collaboration with the Central Veterinary Research Institute at Mukteswar, should carry out comprehensive surveys of disease conditions in the field, and supply requisite material and information for detailed research. As expected, this scheme has provided a valuable liaison between the Central Institute and the field staff, and has proved an efficient agency for the application of the latest methods of disease-control. One of the most outstanding achievements of the staff is the initiation of the new technique of goat-virus vaccination against rinderpest, which is the most dreaded scourge of cattle-breeders in India. This new technique of rinderpest control, which is both cheap and effective, is now adopted as a routine all over the country both as a prophylactic and for the control of outbreaks. Its adoption has resulted in tremendous saving in the cost of immunization, and enabled the veterinary staff to confer protection on a much larger number of cattle than formerly. The work of the Disease Investigation Officers has also brought to light a mass of useful information on many other diseases, some very obscure, which, however, cannot be enumerated within the space of this article.

Besides the disease-investigation officers' scheme, other research schemes relating to helminthological and protozoological problems, investigation into tuberculosis, Johne's disease, contagious abortion, &c., have also been put into operation by the Council.

The various problems of animal nutrition have also been considered by the Council, and schemes relating to mineral metabolism, feeding-values of rice straw and other indigenous fodders, certain food grains, oil-seeds and cakes, and preparation of cattle-feeds from molasses, &c., have been in operation for several years now; results of practical importance are accumulating.

Another important step taken by the Council is the constitution of a Standing Central Fodder and Grazing Committee. The objects of this Committee are to secure systematic and progressive improvement in grazing and grass-land areas, and the conversion of waste lands into useful grazing wherever that is economically possible. Many of the provinces have set up local counterparts of the Central Committee. As

a result, work is now in progress over a large area, in collaboration with the local agricultural and forest departments, designed to secure both the prevention of erosion and the supply of larger quantities of cattle fodder.

(*c*) *Activities of the provinces.*—Every Provincial Government maintains one or more cattle farms where the main work is the systematic improvement of the important local breeds by selective breeding. Attempts were made in the past to cross local cattle with bulls imported from abroad, e.g. Ayrshire, Friesian, and Shorthorn, the object being to introduce factors for high milk production in the progeny. But the deterioration in the constitution in subsequent crosses and other limitations of this system, particularly the impracticability of judicious culling, has led to this policy being abandoned, and attention is now concentrated on the improvement of the indigenous breeds by selection. The Government cattle farms are managed on modern scientific lines, and regular and systematic records are maintained. Surplus bulls are distributed in villages for stud purposes on some sort of premium system, details of which vary from province to province, with the object of grading up the inferior village stock in the locality. For this extension work the supply from the farms is supplemented by purchase of the progeny from approved bulls, when animals of the requisite quality are available, thus affording encouragement to private breeders. These activities are, however, very limited and the total number of approved bulls at stud in the whole of India is not yet sufficiently large to produce an appreciable improvement in the general run of the cattle in the country as a whole. There are in all about 10,000 approved bulls at stud in British India, which is only one-hundredth part of the actual requirements. The personal interest shown by H.E. the Viceroy in cattle improvement and the appeal issued by him have helped to increase the number of approved bulls by about 25 per cent.

The Veterinary Departments of the Provinces and States assist cattle improvement to a very large extent by the control of contagious diseases and the systematic castration of inferior males. Disease has been one of the greatest limiting factors in cattle improvement in India, and serious efforts are being made both in regard to prevention and cure. Rinderpest, which accounts for 60 per cent. of the total mortality from contagious diseases, is the greatest menace, but, as already noted, a cheap and effective weapon of vaccination is now available for use against this plague. Over a million castrations are performed annually by the veterinary staff and the number is increasing steadily.

Results obtained.—Reference has been made in previous sections to the breeds of cattle existing in India and to the organizations at work for their improvement. A review of the results obtained in recent breeding work is presented below. It will show that, small though this work is as compared with the vastness of the live-stock population in India, enough has been done to demonstrate the undoubted potentialities for improvement that Indian cattle possess, and the striking rapidity with which they respond to scientific feeding and management.

Though the villager invariably looks upon a cow as the mother of his working bullocks, a definite classification of the various breeds into

draught, milch, and dual purpose is possible. For many centuries past the Indian village cattle-breeder has undoubtedly paid most attention to draught qualities, with the result that those requiring good specimens of this class of animal have a large range from which to select, as explained earlier in this paper.

In recent years, however, the necessity for providing the Indian population with larger quantities of milk at a cheap rate (the present consumption is stated by Wright [10] to be less than 8 oz. per head per day) has led to a great effort being made towards the development of those breeds which show potentialities for milk production, either alone or in combination with draught qualities.

The Sahiwal, the premier milch breed of India, has received the greatest attention. Pedigree herds of this breed are maintained on many farms and have fully justified the expenditure of time, effort, and money spent on them. Three outstanding Sahiwal herds are those at the Imperial Agricultural Research Institute, New Delhi, the Punjab Agricultural College Farm, Lyallpur, and the Military Dairy Farm, Ferozpore. These herds were established about 25 years ago, and since then the overall average daily yield has increased from 5–6 lb. to 17–20 lb. The average lactation yield started with about 2,000 lb. of milk, and to-day it is over 7,000 lb. The monetary value of this work has been such that proved bulls from the herd belonging to the Imperial Agricultural Research Institute, New Delhi, have been sold for six times the price of an ordinary Sahiwal bull. An analysis made of the 289 lactations completed by the herd of 51 cows which existed at the Ferozpore Farm in 1932 showed that 117 lactations exceeded 6,000 lb., 66 exceeded 7,000 lb., 30 exceeded 8,000 lb., 16 exceeded 9,000 lb., and 6 exceeded 10,000 lb., including two pedigrees which produced between 12,000 and 13,000 lb. The average lactation length was 308 days, calving interval 408 days, and fat percentage of the milk 4·7. The average yield of all farm-bred Sahiwal cows in India during 1937–8 was 5,085 lb. of milk in 308 days. About 45 per cent. of the total number of animals is above this average. The high standard to which this breed has been developed is well shown in the photograph of 'Mudini' (Plate 6, *a*), a Sahiwal cow belonging to the Military Farms Department and winner of a supreme championship at the All India Cattle Show of 1940.

A herd of Tharparkar (Plate 6, *c*) and a herd of Hariana (Plate 2, *b*) cattle were established at the Karnal Sub-station of the Imperial Agricultural Research Institute in 1923. The average yield of the foundation herd was 8·8 lb. during lactation. By 1934 this rose to 13·2 lb. in the Tharparkar herd and 14·1 lb. in the Hariana herd; individuals have yielded up to 8,734 lb. in the former and 7,412 lb. in the latter herd. This Hariana herd is now located at the Imperial Veterinary Research Institute, Izatnagar, whilst other herds of this breed are to be found at the Hissar Cattle Farm, Punjab, and at the Madhurikund Farm in the United Provinces. Other pedigree herds of Tharparkar cattle are maintained at the Patna Veterinary College and the Agricultural Farm, Kanke, both in Bihar. The latest averages for all Tharparkar herds of farm-bred animals in India is 4,056 lb. of milk in 267 days, the proportion above

the average being 46 per cent. Corresponding figures for Hariana are 3,426 lb. of milk in 308 days and 32 per cent.

The Sindhi breed (Plate 6, *b*) is maintained on many farms in India, some of the best-known herds being those at the Willingdon Cattle Farm, Karachi, the Livestock Research Station, Hosur, Madras Presidency, the Central Dairy Research Institute, Bangalore, and the Agricultural Institute, Allahabad, United Provinces. It is a breed which thrives under all climatic conditions in India, and is extensively used for grading up local inferior stock. The average of last completed lactations of farm-bred Sindhis is 3,934 lb. in 325 days. The highest yield reached is 9,283 lb. of milk in a lactation of 351 days. The bullocks of this breed have also a good reputation for work.

No publication on milk production in India would be complete without a reference to the capabilities of the Indian buffalo (Plate 6, *d*), which, as Kartha [11] has shown, is in many respects a more economical milk producer than either indigenous or cross-bred cattle. The average amount of butter-fat in buffalo milk may be placed at 7 per cent., and these animals are able to keep up their supply of this rich milk and maintain their condition in places where cattle rapidly deteriorate. Of the different breeds of buffaloes in India, the Murrah has been most developed for milk production.

The following table shows the averages of latest lactations and the highest lactation obtained in this breed of buffaloes and also in some of the less developed breeds of cattle:

	Average	*Highest*
Murrah buffalo . .	4,037 lb. in 277 days	8,252 lb. in 318 days
Gir . . .	3,721 lb. in 333 days	5,188 lb. in 366 days
Ongole . . .	3,164 lb. in 303 days	5,237 lb. in 365 days
Kankrej . . .	3,159 lb. in 303 days	6,073 lb. in 358 days

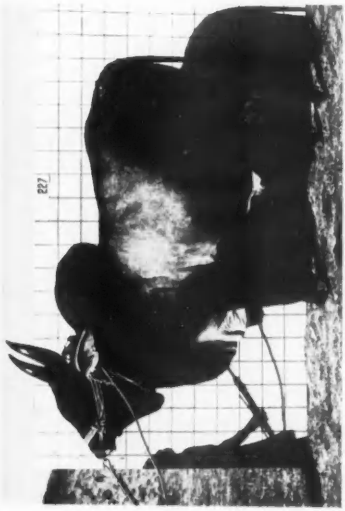
In order to obtain a correct picture of the improvement which has been obtained in some of India's milch breeds it is necessary to compare the yields obtained in farms run on modern lines with the performances noted in village breeding-areas. The following are the details of some breeds made available by an inquiry conducted in certain typical breeding tracts and made the subject of a special report [1]:

Breed	*Average daily yield lb. (average of 7 days)*	*Average lactation-length in months*	*Average dry period in months*
Sahiwal . .	4·72	10·43	7·24
Hariana . .	4·46	7·62	7·62
Kankrej . .	3·90	7·90	10·21
Ongole . .	4·64	9·54	9·47
Murrah buffalo .	11·21	8·65	6·10

The interesting point which arises out of this inquiry is that, where village cattle are concerned, there is no significant difference in the levels of production of these different breeds, except the Murrah buffalo. This

b. Kankrej Bullock

d. Malvi Bull



a. Kankrej Bull

c. Lyre-horned Malvi bull, *ca.* 3000 B.C.

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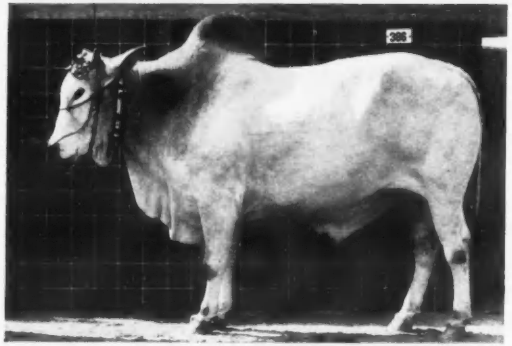
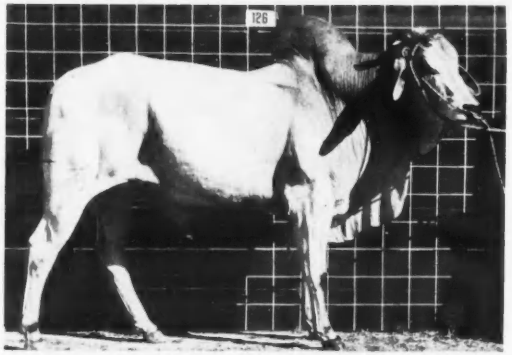
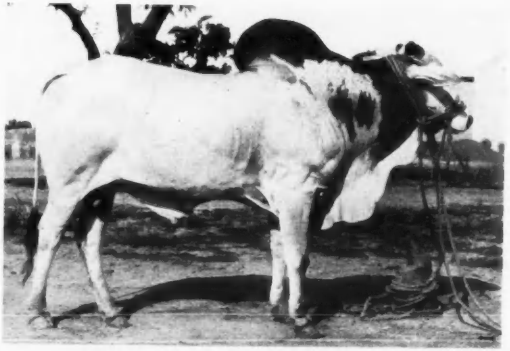


a. Bhagnari Bull

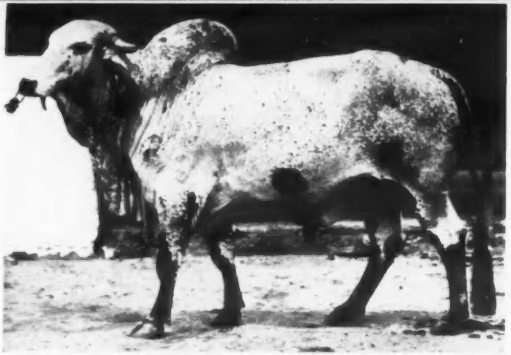


b. Hariana Bull

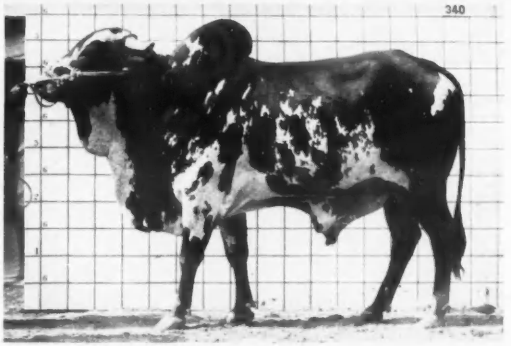
c. Krishna Valley Bull



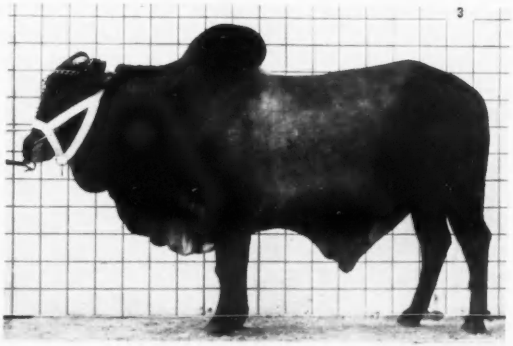
d. Nyole Breeding Bull



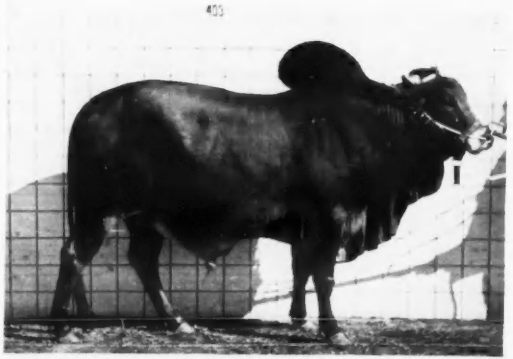
a. Gir Bull



b. Nimari Bull

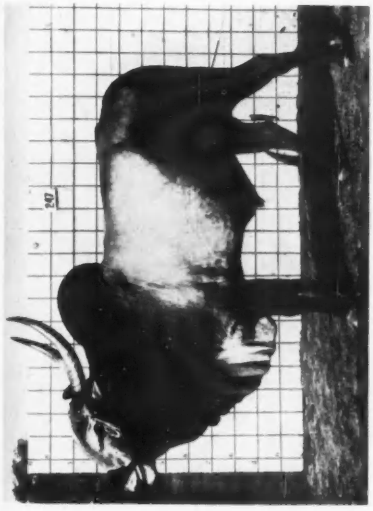


c. Sahiwal Bull



d. Sindhi Bull

b. Hallikar Bull



a. Khillari Bull

d. Alumbadi Bull

c. Kangayam Bull

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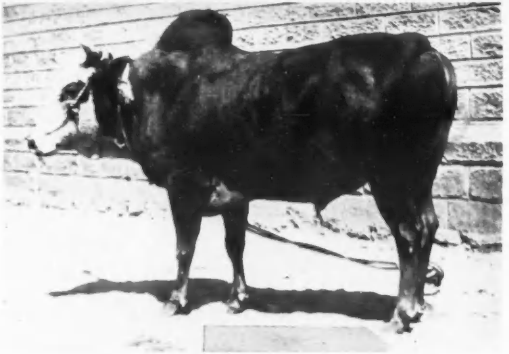
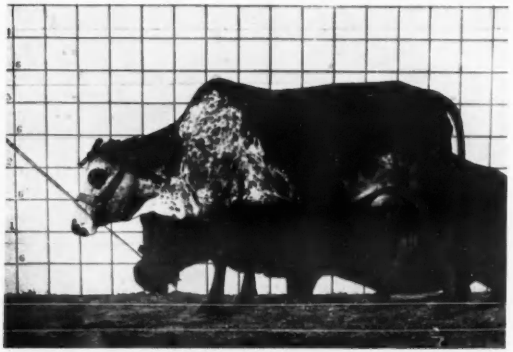
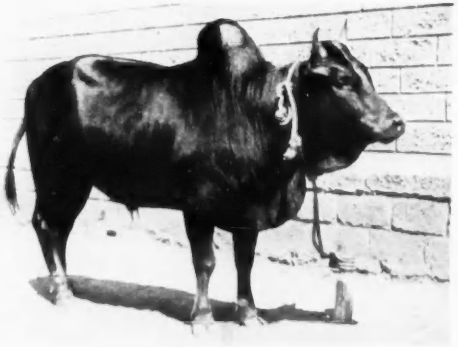
a. Afghan Cow



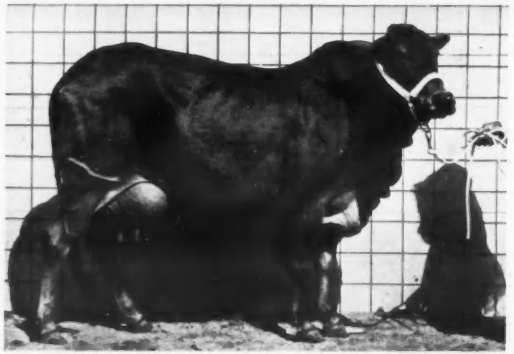
b. Afghan Bull



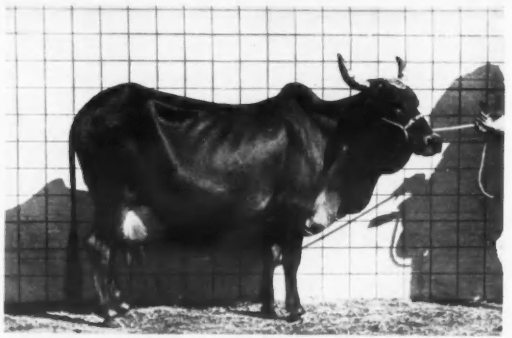
c. Zohani Cow



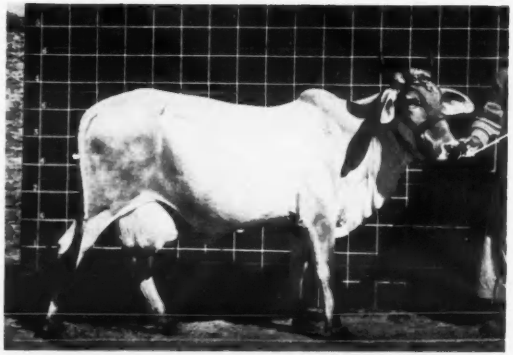
d. Kumaon Hill Bull



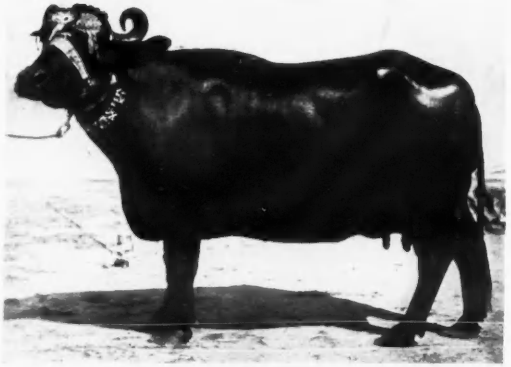
a. Sahiwal Cow



b. Sindhi Cow



c. Tharparkar Cow



d. Murrah Buffalo Cow

exception is largely explained by the fact that the buffalo is kept almost entirely for milk production and therefore more attention is paid by the villager to the rearing of heifer buffalo calves than to cow calves. Moreover, as the buffalo is not a sacred animal, some culling of this species has always been practised by the villager.

The similarity in the yield of village cattle of the above breeds leads to the conclusion that the differences noticed in different herds may be indicative not so much of the intrinsic values or potentialities of the different breeds as milk producers, as of the differing amounts of attention paid to them. From the high levels already reached by certain breeds it is reasonable to assume that when equal attention is paid to all those showing potentialities as milk producers, they will respond equally well and provide breeders with satisfactory results. Another striking fact is the rapid rate of evolution which seems to be possible in these Indian breeds of cattle. The Sahiwal has reached in 25 years a level of milking performance which foreign breeds would have taken more than a century to attain.

Acknowledgements

In the compilation of this article I have received much useful help from my assistants, Mr. H. B. Shahi and Mr. K. P. R. Kartha. The Library and Office of the Imperial Council of Agricultural Research have been used freely for records and photographs, and in this connexion it may be stated that the Animal Husbandry Bureau of this Council is now in a position to give detailed information to anyone interested in Indian breeds of cattle and other live stock. Inquiries should be addressed to the Secretary, Imperial Council of Agricultural Research, New Delhi, India.

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A FACTORIAL EXPERIMENT ON THE MANURING OF YOUNG TEA

E. K. WOODFORD AND H. R. COOPER

(*The Tocklai Experimental Station, Indian Tea Association, Cinnamara, Assam*)

Introduction.—The evidence obtained at the experimental stations of the three chief tea countries shows that nitrogen is the main requirement for growth of tea. In NE. India and in Java the response to phosphoric acid is very small, but in Ceylon a significant increase is produced by 20 lb. of phosphoric acid per acre, though 40 lb. per acre yielded no further increase [1]. In Ceylon and Java, potash appears to have no effect on the crop [2, 3], whilst in NE. India, 15 lb. potash per acre produced a small but significant increase, which was not further increased by 30 or 60 lb. potash [4]. Experiments in all three countries show that the increase in tea crop is proportional to the dressing of nitrogen used, up to very high limits, except a few on naturally rich humus soils or under very heavy shade of leguminous trees [2, 4, 5].

Since large areas of old tea are now being replanted with younger and more vigorous plants of 'jats' (commercial varieties) giving higher yields and better quality, it is necessary to know whether the requirements of very young tea may not differ from those of mature tea.

Two jats of tea were therefore used in the experiments, because there might be a differential response to manuring. The jat name is that of a garden growing differing seed-bearing trees interfertile among themselves, and jats therefore may vary genetically from year to year. Jat comparisons, consequently, are of dubious permanent economic importance.

There is no such thing as varietal classification in tea, and all jats are heterogeneous mixtures; but jats can differ very greatly in average yielding-capacity, in average quality, and in average resistance to adverse conditions and to disease.

The planter makes a very rough distinction among 'indigenous' bushes, between 'light-leaf' types reputed to give good yields of good quality in favourable climates, and 'dark-leaf' types reputed to be more hardy, but to give poorer average quality. A plant of 'China' or 'China-hybrid' character, occurring among either of these, is looked upon as 'not true to type', and rejected from the nursery if recognized.

The two jats selected would be considered typical 'light-leaf' indigenous and 'dark-leaf' indigenous jats, respectively; but the results obtained may not apply to all 'light-leaf' or all 'dark-leaf' jats.

Design of the Experiment

The manurial treatments were: nitrogen at two levels, N_{20} and N_{60}; phosphoric acid at three levels, P_0, P_{20}, P_{60}; potash at three levels K_0, K_{20}, K_{60}; and two jats of bushes, Silbhetta dark-leaf (D) and Silbhetta light-leaf (L). The suffixes to the letters indicate the pounds of manure applied per acre; nitrogen was applied as sulphate of ammonia, 'phosphoric acid' as superphosphate, and 'potash' as sulphate of potash.

The 36 treatment combinations of this $2 \times 2 \times 3 \times 3$ experiment were replicated four times in 12 sub-blocks of 12 plots each. Since 9 is not a factor of 12 it was impossible to keep clear the interaction between phosphorus and potassium and the higher-order interactions associated with these two treatments. The first-order interaction was the only one considered likely to be of importance, and the design of the experiment, illustrated below, made it possible to estimate seven-eighths of the information on this interaction. Within sub-blocks, treatments were randomized.

TABLE 1. *Arrangement of Treatments in Blocks*

Jat and Nitrogen combination	*Phosphorus and potassium combinations*											
	Blocks											
	I			*II*			*III*			*IV*		
	a	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*
1	1	2	3	1	2	3	1	2	3	1	2	3
	5	6	4	5	6	4	5	6	4	5	6	4
	9	7	8	9	7	8	9	7	8	9	7	8
2	2	3	1	3	1	2	2	3	1	3	1	2
	6	4	5	4	5	6	6	4	5	4	5	6
	7	8	9	8	9	7	7	8	9	8	9	7
3	3	1	2	2	3	1	2	3	1	3	1	2
	4	5	6	6	4	5	6	4	5	4	5	6
	8	9	7	7	8	9	7	8	9	8	9	7
4	1	2	3	1	2	3	3	1	2	2	3	1
	5	6	4	5	6	4	4	5	6	6	4	5
	9	7	8	9	7	8	8	9	7	7	8	9

Combinations: Jat and nitrogen
Dark-leaf $N_{20} = 1$
Dark-leaf $N_{60} = 2$
Light-leaf $N_{20} = 3$
Light-leaf $N_{60} = 4$

Combinations: Phosphoric acid and potash
P_0K_0 1
P_0K_{20} 2
P_0K_{60} 3
$P_{20}K_0$ 4
$P_{20}K_{20}$ 5
$P_{20}K_{60}$ 6
$P_{60}K_0$ 7
$P_{60}K_{20}$ 8
$P_{60}K_{60}$ 9

4 replications I, II, III, and IV.
Each replication divided into 3 sub-blocks, *a*, *b*, and *c*.

Details of the Experiment

The experiment was laid down in 1935 at the Borbhetta Field Experimental Station of the Scientific Department of the Indian Tea Association. The soil is a sandy, reddish-grey, new alluvium of the Assam Valley, lying on a compact yellow subsoil. The area had previously been used as public grazing land, was poor and very patchy. Before the tea was planted the land was levelled by removing the soil from the bottom and sides of the holes and replacing it on top of the subsoil used for filling. All white-ant mounds were removed to a depth of one foot below the soil surface, the queen ants being dug out and destroyed. The alkaline soil remaining below this level was treated with

the amount of sulphur required to bring it to the average acidity of the adjacent subsoil; and over it normal top-soil was spread to level the land. Tea will not grow on untreated 'white-ant' soil. The whole was then cultivated, sown with *Tephrosia candida*, and left to consolidate through one season of rain, before hoeing in the *Tephrosia* and planting tea. The use of this leguminous plant may account for the small consumption of additional nitrogen by the tea in early years. Other relevant details are:

Plots.—Plants 96 (8 × 12), planted $4\frac{1}{4} \times 4\frac{1}{4}$ ft. triangular. The plots, each of 0·0344 acre, were not separated by guard-line bushes, but a single line of these surrounded the whole area. Plots were separated by low walls of earth in one direction, and by drains 3 ft. deep and 5 in. wide in the other direction.

Manuring.—The fertilizers were applied by hand over circles of 15 in. radius about the collar of each plant and lightly forked in, both in April 1936 and in June 1937. In 1938 and 1939 the manures were broadcast over the whole plot.

Growth-measurements.—(*a*) Weight of prunings. (*b*) Weights of leaf plucked weekly during the growing-seasons 1938 and 1939. All shoots of two-leaves-and-a-bud above a predetermined plucking-level were weighed, and all weighments were of fresh material, weighed immediately after the plucking or pruning of each plot was completed.

Cultural treatments.

1934, Nov. Seed planted in nursery.

1935, Oct.–Nov. Seedlings transplanted to experimental area.

1936, Feb. Plants pruned to 8 in. from the ground. This is not a normal cultural process, but was adopted in order to start the experiment with plants of a standard height.

Apr. Manures applied.

Apr. Hail damage. Many plants died, as the hail came just after the seedlings had flushed, following the severe prune. Dead plants were replaced by plants from the same nursery already cut to 8 in.

1937, Apr. Bushes suffered from a bad attack of Red Spider (*Tetranychus bioculatus* Wood-Mason).

June. Manure applied.

Oct. Bushes pruned at 18 in. from the ground. All prunings above 18 in. weighed.

1938, Apr. Bushes again suffered from a bad attack of red spider.

May. Attack by 'red rust' (*Cephaleuros parasiticus* Karst) caused plucking to cease.

June. Manures applied.

June. Plants cut across at 32 in. from the ground-level, and prunings weighed. Pruning in June is not a normal cultural practice, but was carried out in this case in order to reduce to normal plucking-level the few bushes which had grown during the bad attack of red rust following red spider. For the remainder of season 1938, bushes were plucked weekly to the 32 in. level, leaving only the 'janam' (cataphyll).

Dec. Pruned at 20 in. from the ground and prunings weighed.

1939. Bushes were plucked weekly starting at 30 in. from the ground.

Results

Weights of prunings.—The total weights of prunings for each treatment at each of the three pruning times are given in Table 2.

TABLE 2. *Weight of Prunings (lb./acre)*

Treatment		*Oct. 1937*	*June 1938*	*Dec. 1938*
Jat:	Light	*2,188*	*1,642*	*3,757*
		(141)	(228)	(225)
	Dark	*1,824*	*1,036*	*3,064*
Nitrogen:	N_{20}	*2,113*	1,437	3,409
		(141)	(228)	(225)
	N_{60}	*1,920*	1,241	3,412
Phosphoric acid:	P_0	1,990	*1,152*	*3,201*
	P_{20}	2,052 (173)	1,389 (280)	*3,494* (276)
	P_{60}	2,006	*1,476*	3,536
Potash:	K_0	*1,814*	939	*3,003*
	K_{20}	*2,009* (173)	*1,184* (280)	*3,378* (276)
	K_{60}	*2,225*	*1,893*	*3,850*

Differences required for the 1 per cent. point of significance are given in parentheses. Treatment results significantly different from one another are printed in italics.

The results show that there was a highly significant difference between jats on all three occasions, the lighter-leaved jat always yielding a greater weight of prunings. The higher dressing of nitrogen decreased the weight of prunings in 1937, but this effect was not apparent in the following year. Phosphorus had a negligible effect in 1937 but increased the weight of prunings in 1938. The larger dressing of phosphoric acid was only slightly better than the smaller dressing. Potash had a very marked effect on the growth of the bushes as measured by the weight of prunings. The increase was approximately proportional to the amount of potash applied to the soil on all three occasions.

The only significant interaction was that between jat and potash, in June 1938. The weights of prunings in pounds per acre for these plots were:

	Jat	
	Light	*Dark*
Potash: K_0	1,023	855
K_{20}	1,400	968
K_{60}	2,501	1,285

Difference for significance 5 per cent. point = *396*

and indicated that the potash was of more benefit to the light-leaved jat than to the dark-leaved. A similar result was obtained for the weight of leaf in both 1938 and 1939; it is discussed later in conjunction with the results of the incidence of red spider.

Weight of leaf.—Leaf, consisting of all shoots of two-leaves-and-a-bud above the plucking-surface was removed and weighed weekly from July

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to November in 1938 and from March 24 to December 1 in 1939. The total weights of leaf plucked per acre for each main effect are recorded in Table 3.

TABLE 3. *Pounds of Fresh Leaf Plucked (per acre)*

Treatment		*1938*	*1939*
Jat:	Light	*419*	*1,816*
		(35)	(71)
	Dark	*310*	*1,445*
Nitrogen:	N_{20}	366	*1,526*
		(35)	(71)
	N_{60}	361	*1,744*
Phosphoric acid:	P_0	342	1,582
	P_{20}	370 (45)	1,652 (92)
	P_{60}	381	1,669
Potash:	K_0	320	*1,434*
	K_{20}	*352* (45)	*1,628* (92)
	K_{60}	*430*	*1,841*

Differences required for the 1 per cent. point of significance are given in parentheses. Adjacent treatment results significantly different from one another are printed in italics.

These results are very similar to those for the weights of prunings. The difference in favour of the light-leaf jat against the dark-leaf was again highly significant in both years. In 1939 the dark-leaved jat started growth earlier in the season and was yielding more leaf until May 5, after which date the light-leaved jat was always ahead, the percentage difference reaching a maximum around October 20. Similar results have been recorded in other experiments where dark- and light-leaved jats have been compared.

The bushes on the plots receiving 60 lb. of nitrogen per acre yielded significantly more leaf than those receiving only 20 lb. nitrogen in 1939, although there was no difference between the effects of these two treatments in 1938. This increase was evenly distributed over the whole of the growing-period of 1939.

The response to phosphoric acid was negligible in both years. The effect of potash was very marked; approximately 89 per cent. of the total variance in 1939 due to the effect of potash was attributable to the linear regression.

In 1939 there was a significant interaction between jat and nitrogen. The results in pounds per acre, were:

	Light	*Dark*
N_{20}	1,248	1,039
N_{60}	1,476	1,140

Significant difference 5 per cent. point = 79·6

and showed that the light-leaved jat benefited more by the larger dose of nitrogen than the dark-leaved.

The interaction between jat and potash also was significant in 1939.

The results indicate that the light-leaved jat benefited more from potash than the dark-leaved jat:

	K_0	K_{20}	K_{60}
Light	1,539	1,823	2,087
Dark	1,328	1,434	1,597

Significant difference 5 per cent. point = 130 lb.

The only other interaction which approached the 5 per cent. level of significance was that between nitrogen and phosphoric acid in 1939, and this indicated that the phosphatic fertilizer was effective only in the presence of the higher nitrogen dressing. Even with the higher dressing of nitrogen, the lower dressing of phosphorus is as effective as the higher. The results were:

	P_0	P_{20}	P_{60}
N_{20}	1,539	1,508	1,527
N_{60}	1,625	1,796	1,811

Significant difference 5 per cent. point = 130 lb.

The Incidence of Red Spider (Tetranychus bioculatus)

During April and May, 1937 and 1938, all the bushes in the experimental area suffered a severe attack of one of the major pests of tea, red spider. In 1938 the attack was worse than in 1937, and not a single bush was free from the mite.

A rough measure of the damage done by red spider to a bush can be estimated visually by a trained observer. The attacked portions of a normally green leaf are reddened, and turn brown when they die as the result of attack. Very badly attacked bushes completely cease growth, but unattacked or slightly attacked branches carry fresh green shoots.

At the height of the attack in 1937, a strip of 2×12 bushes down the length of each plot was examined and each bush was numbered according to the following classification [6]: 0 unattacked; 1 slightly attacked; 2 moderately attacked, but shoots still growing; 3 badly attacked, shoots not growing. In 1938 when the attack was much worse, every bush in the experiment was examined and numbered according to the following classification; 0 unattacked; 1 slightly attacked; 2 moderately attacked; 3 badly attacked, but some shoots still growing; 4 badly attacked: all the leaves red or brown, and no shoots growing.

The results are presented in Table 4. Such a method of estimation is subject to much personal bias, and the statistical analysis of the results may not always be mathematically ethical, yet it is believed that in the present instance it does help to elucidate the effect of the treatments on the incidence of red spider.

That the red-spider attack was significantly worse on the dark-leaved jat in both years may be partly due to the fact that the dark-leaved bushes grow more vigorously during the early part of the season. Red spider

feeds mainly on mature leaves. The darker-leaved jat might therefore provide conditions more favourable for the multiplication of red spider earlier in the season, so that the peak of the attack could be reached earlier on it than on the light-leaved jat. A break in the weather acting adversely on the red spider, e.g., heavy rain, might therefore cause the light-leaved bushes to miss the full effect of the attack.

TABLE 4. *Incidence of Red Spider*

Treatment		*1937*	*1938*
Jat:	Light	*1,566*	*15,806*
		(169)	(542)
	Dark	*2,138*	16,356
Nitrogen:	N_{20}	*1,748*	15,881
		(169)	(542)
	N_{60}	*1,956*	16,281
Phosphoric acid:	P_0	*1,391*	*10,991*
	P_{20}	*1,152* (137)	10,741 (443)
	P_{60}	1,162	*10,427*
Potash:	K_0	1,192	10,826
	K_{20}	1,250 (137)	*10,946* (443)
	K_{60}	1,242	*10,390*

Difference required for the 1 per cent. point of significance are given in parentheses. Treatment results significantly different from one another are printed in italics.

The higher dose of nitrogen increased the attack of red spider, significantly in 1937, but not in 1938.

The estimations gave a significantly lower count on the plots receiving phosphoric acid in both years. Potash decreased the amount of red spider during 1938. In addition the interaction jat × potash was highly significant in 1938. The results for this interaction are given below and indicate that potash reduced the incidence of red spider only on the light-leaved jat.

	Potassium		
	K_0	K_{20}	K_{60}
Light	5,470	5,414	4,922
Dark	5,356	5,532	5,468

Difference required for significance 5 per cent. point = 191.

Discussion

Efficiency of the design.—In all the results the variance between blocks was large as compared with the error variance, and it is clear that the arrangement of the treatments into 12 blocks instead of 4 increased the precision of the experiment. Yates [7] has shown how the magnitude of this gain in precision can be measured by replacing the 'treatment mean square' by the 'error mean square', and then calculating what the error would have been had there been no confounding. This has been done for the 1939 leaf-weights, using a block variance which represents only

the differences of the blocks forming the same replication, and the results show that the gain in information due to confounding is about 26 per cent.

Growth as total dry matter produced.—The results have been expressed on a dry-weight basis by assuming that the leaves, skiffings, and prunings contained 23, 30, and 60 per cent. of dry matter respectively.

TABLE 5. *Yield of Dry Matter (per acre)*

Treatment		*Prune October 1937*	*Skiff June 1938*	*Leaf 1938*	*Prune October 1938*	*Leaf 1939*	*Total*
Jat:	Light	787·7	492·6	96·4	1,352·5	417·7	3,146·9
	Dark	656·6	310·8	71·3	1,103·0	332·4	2,474·1
Nitrogen:	N_{20}	760·7	431·1	84·2	1,227·2	351·0	2,854·2
	N_{60}	691·2	372·3	83·0	1,228·3	401·1	2,775·9
Phosphorus:	P_0	716·4	345·6	78·7	1,152·4	363·9	2,657·0
	P_{20}	738·7	416·7	85·1	1,257·8	380·0	2,878·3
	P_{60}	722·2	442·8	87·6	1,273·0	383·9	2,909·5
Potassium:	K_0	653·0	281·7	73·6	1,081·1	329·8	2,419·2
	K_{20}	723·2	355·2	81·0	1,216·1	374·4	2,749·9
	K_{60}	801·0	567·9	98·9	1,386·0	423·4	3,277·2

The dark-leaved jat grew at a slower rate throughout the period and produced less leaf and pruning wood.

Nitrogen at the higher level (60 lb. per acre) depressed growth until June 1938. During the remainder of 1938, growth was the same for both levels of nitrogen. From the beginning of 1939, when the plants were 4 years old from seed, the higher level of nitrogen significantly increased growth.

It is believed that young tea generally would benefit from the higher dressing of nitrogen at an earlier stage. Plants with few leaves cannot use much nitrogen.

These particular plants suffered a severe set-back from hail in April 1936, which stripped the young growth made after the severe prune in February. This set-back was accentuated by the manuring shortly before the hail. Experiments have shown that sulphate of ammonia depresses growth of mature tea for three weeks after application [4]. From this sequence of misfortunes many plants died, and the remainder were greatly weakened. The number of deaths in 1936 was 10·5 per cent. where 20 lb. nitrogen had been applied, and 12·6 per cent. where 60 lb. nitrogen had been applied, the difference being significant on the 5 per cent. level. Neither superphosphate nor sulphate of potash affected the number of deaths.

Phosphorus as superphosphate had no pronounced effect on growth, although in all the results recorded slightly increased weights of leaf and prunings were apparent. The cumulative effect is shown in Table 5. The application of 20 lb. of phosphoric acid per acre did significantly increase the weight of prunings at the end of 1938, but this treatment

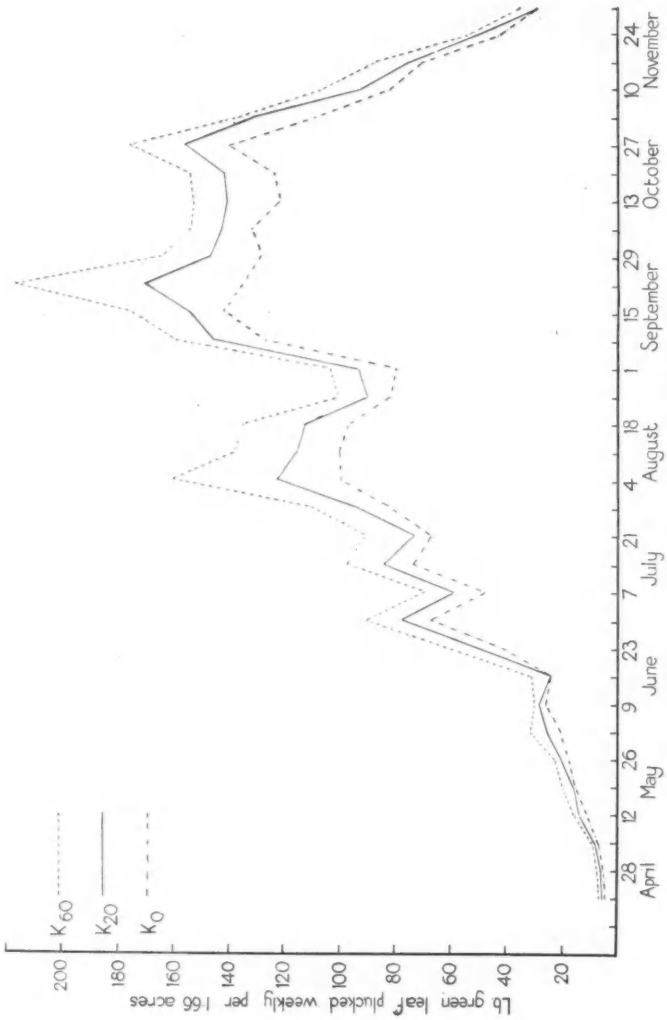

FIG. 1 Yields of tea at three levels of potash manuring.

produced significant reduction of attack by red spider, and its effect on growth in 1938 may have been partly due to this cause.

The soil at Borbhetta is very low both in available phosphoric acid and potash, and other plants, particularly legumes and grass, give large responses to phosphatic manures. In the present experiment, although no accurate records were made, it was noticed that on the plots receiving superphosphate grass and weeds grew much thicker and taller than on plots receiving no superphosphate. This secondary effect of phosphate was probably not important in reducing tea crop in this experiment, as the plots were frequently cleaned by hoeing. It might, however, be of much greater importance on commercial tea estates where it is not always possible to hoe as frequently as on experimental plots.

Potash increased significantly the yields both of prunings and of leaf on all occasions, an effect which is not in agreement with the results of experiments on mature tea. This difference between the behaviour of young and mature bushes is difficult to understand because 4-year-old plants undoubtedly use less potassium for growth than mature plants. It is known, however, that potassium is particularly necessary for meristematic growth. It has also been shown that potassium is extremely mobile in the plant and is readily transported from the older tissues to the younger and more actively growing regions [5]. It is possible, therefore, that young tea plants need a higher concentration of available potassium in the soil because their roots can absorb from a smaller volume of soil, while they have, in proportion, less old leaves and wood from which they can draw their supplies of potassium for new growth. There is also evidence that the lower layers of the soil at Borbhetta, which can be reached by the roots of the mature plants only, are richer in potassium.

The yields for the three levels of potash at each plucking in 1939 are presented graphically in Fig. 1. It can be seen that the potash increased yield evenly throughout the growing-season and that there was no tendency towards more marked effects from potash either at the end or at the beginning of the season.

It still remains to be seen whether the effect of potash on early growth persists when the bushes are mature; but the expectation is that bushes growing more vigorously when young will remain better leaf-yielders when mature. If the effect of the potash proves only to bring young tea more quickly into bearing, it still will be valuable.

Summary

1. Results are described of a multiple-factor experiment on young tea, carried out over four years, to investigate the response of two types of tea plants to nitrogenous, phosphatic, and potassic manures.

2. The data show that the light-leaved type of plant yielded more prunings and more leaf throughout the experiment, and that it responded to both nitrogenous and potassic manures more than the dark-leaved type; but all treatment effects are in the same direction for both jats.

3. Nitrogen had a depressing effect on the weight of prunings in 1937, no effect on crop of leaf in 1938 or on weight of prunings at the end of 1938, but increased the weight of leaf in 1939.

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4. Phosphoric acid had no significant effect on weight of leaf plucked, but 20 lb. of phosphoric acid did increase the weight of the prunings at the end of 1939. The interaction between phosphorus and nitrogen was significant in 1939, and indicated that phosphorus was beneficial to the plants only when they received the higher dose of nitrogen.

5. Potash increased the growth of the plants, as measured by the weight of leaf and prunings, throughout the experiment, and the increased growth was almost directly proportional to the amount of potassium applied.

6. The incidence of red spider (*Tetranychus bioculatus*) during 1937 and 1938 is discussed, and it is shown that there was significantly more red spider on the dark-leaved jat, in both years, and on the bushes receiving the heavier dose of nitrogen in 1937. Phosphorus reduced the attack in both years, and potash in 1938.

Acknowledgement

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THE NUTRITIVE VALUES OF SOME TANGANYIKA GRASSES

M. H. FRENCH

(*Veterinary Laboratory, Mpwapwa, Tanganyika Territory*)

GRASSES are not only the basis but almost the sole constituent of live-stock diets in Tanganyika Territory, where supplementary feeding is practised only on European farms and not at all amongst the vast herds of native-owned stock. The latter get their livelihood almost entirely from grass, helped out by crop-residues, weeds, leaves, and tree seeds; and so grass must be regarded as the raw material for all animal products, such as meat, milk, hides, skins, ghee, and clarified butter. In addition, because live stock are so bound up with tribal customs and represent a large part of the native-owned capital of the Territory, much internal trade, as well as tax payments, depends on their welfare, and this in turn depends on the grazing conditions.

Many grasses have been studied at Mpwapwa, and this article presents data on the chemical composition, digestibility, and feeding-value of a few grazing and fodder grasses. These grasses were growing in adjacent plots on the same type of soil, and the investigation was carried out during the wet season of 1938; all species were therefore subjected to the same environmental conditions.

With the seasonal distribution of rainfall in this Territory, grasses grow quickly when the rainy season begins, and usually get beyond their best grazing-stage, because stock cannot eat them quickly enough. Large areas grow to maturity, dry off *in situ* as the dry season advances, and are eaten during the dry winter. The long dry season enforces a dormant period and growth is confined to the rainy season (4–5 months). Close rotational grazing is not practised by the natives, and though their stock-numbers are inadequate to keep down the summer growth of grass, the dry-season grazings are often overstocked. It seemed, therefore, that instead of determining feeding-values under conditions of regular rotational grazing, more information would be obtained if existing grazing practices were copied. The grasses have been examined at the grazing-stage (up to 12 in. high), at a late grazing-stage (1–1½ ft. high) to represent grass which has grown too quickly for stock to eat down, and at the haymaking stage (2½–3 ft. high). In addition, two fodder grasses, suitable for soiling purposes, have been included and are grouped with the taller grazing grasses. This grouping according to height is not entirely satisfactory, but neither would be grouping according to stage of maturity; and grouping by height does allow a rough correlation with existing grazing practices.

Digestibility of the grasses was determined on pairs of adult male native sheep, and determinations of dry matter were made daily during the period of the trials. These dry-matter residues were collected and analysed. All figures have been calculated on a SiO_2-free dry-matter basis so as to eliminate the variable soil contamination.

TABLE 1. *Composition and Digestibility Coefficients of Grasses (SiO_2-free, dry-matter basis)*

	Composition					*Digestibility Coefficients*						
	Crude protein	*Ether-extract*	*N-free extract*	*Crude fibre*	*Soluble ash*	*Crude protein*	*Ether-extract*	*N-free extract*	*Crude fibre*	*Soluble ash*	*Dry matter*	*Organic matter*
Cynodon plectostachyum	20·25	3·03	44·81	23·97	7·94	75·67	45·12	65·95	65·84	61·76	66·93	67·37
Digitaria Pentzii	14·94	3·20	42·82	30·16	8·88	78·31	70·84	75·80	77·69	71·58	76·22	76·67
,, ,,	9·24	2·03	48·57	33·59	6·57	57·38	34·47	68·72	72·73	58·92	67·69	68·30
,, ,, (2nd cut)	7·28	2·43	47·88	37·97	4·44	51·00	54·77	55·68	66·11	36·59	59·09	60·14
Leerzia hexandra	10·76	1·94	55·25	27·20	4·85	42·11	31·62	70·04	57·29	49·55	63·01	63·69
Panicum maximum (type B)	9·15	1·65	50·58	31·19	7·43	62·29	29·04	64·22	68·57	66·96	64·98	65·80
Pennesetum purpureum	10·39	2·69	46·48	31·44	9·00	57·65	47·70	67·87	70·66	75·19	67·80	67·07
Cydondon plectostachyum (2nd cut)	11·64	1·40	48·94	32·15	5·87	70·26	20·55	60·00	57·29	62·46	59·91	59·75
Cenchrus ciliaris (type D)	11·64	2·78	43·95	33·93	7·70	70·33	78·18	68·52	71·59	76·43	70·65	70·16
Chloris gayana	10·06	1·83	46·94	34·36	6·81	65·25	41·71	73·70	78·99	56·37	73·04	74·11
,, ,, (2nd cut)	7·50	1·10	45·64	41·03	4·73	59·47	29·95	59·52	70·30	55·70	63·75	64·15
Paspalum dilatatum	7·19	1·72	51·96	34·17	4·96	46·06	52·64	68·75	71·94	55·97	67·30	67·90
,, ,, (2nd cut)	6·63	1·65	53·69	34·16	3·87	50·23	49·57	73·75	71·35	56·06	68·67	69·18
Andropogon caricosus (2nd cut)	7·58	1·68	46·66	39·74	4·34	50·06	60·10	61·67	72·02	57·31	64·84	65·18
Panicum maximum (type B)	9·31	1·54	46·30	34·46	8·39	41·16	13·80	56·89	69·86	46·32	58·35	59·45
Pennesetum purpureum	9·54	1·20	49·43	30·37	9·46	50·97	39·85	58·49	57·15	69·85	58·22	57·00
Cynodon plectostachyum	11·53	2·08	47·51	31·72	7·16	69·73	32·44	50·40	60·31	82·01	57·66	55·79
Cenchrus ciliaris (type D) (2nd cut)	11·65	2·06	41·92	36·35	8·02	75·16	70·83	69·49	74·54	79·33	72·80	72·23
,, ,, (type B) (2nd cut)	9·03	1·89	44·36	39·34	5·38	66·04	57·91	69·06	75·78	62·75	71·01	71·48
Panicum maximum (type B)	5·61	1·50	45·48	41·76	5·65	49·04	45·18	50·79	60·55	62·20	55·30	54·93
Pennesetum purpureum	7·75	1·12	46·88	38·99	5·26	45·75	29·52	48·80	55·69	50·44	51·12	51·15

The height of the grasses extended to 12 in. in the first group, to 1½ ft. in the second group, from 2½ to 3 ft. in the third, and from 4 to 8 ft. in the fourth.

TABLE 2. *Nutritive Values of some Tanganyika Grasses* (SiO_2-*free dry-matter basis*)

	Grass species	*Height of grasses*	*Stage of maturity*	*Digestible protein*	*Starch equivalent*
Short grass	*Cynodon plectostachyum*	8–12 in.	No flowering heads	15·32	49·14
	Digitaria Pentzii	4–6 ,,	,, ,,	11·70	54·75
	,, ,,	6–9 ,,	Few flowering heads	5·30	45·73
	,, ,, (2nd growth)	10–12 ,,	Anthers emerged	3·71	37·40
	Leerzia hexandra	6–10 ,,	No flowering heads	6·98	45·88
Medium-length grass	*Panicum maximum*, type B	1–1½ ft.	No flowering heads	5·70	42·81
	Pennesetum purpureum	1–1½ ,,	,, ,,	5·99	44·60
	Cynodon plectostachyum (2nd growth)	1–1½ ,,	Few flowering heads	8·09	37·86
	Cenchrus ciliaris, type D	1–1½ ,,	Anthers showing	8·18	47·74
	Chloris gayana	1–1½ ,,	Few flowering heads	6·56	50·49
	,, ,, (2nd growth)	1–1½ ,,	,, ,,	4·45	38·20
	Paspalum dilatatum	Leaves 1 ft.	,, ,,	3·31	46·69
	,, ,, (2nd growth)	,, 1 ,,	,, ,,	3·33	48·54
	Andropogon caricosus (2nd growth)	,, 1 ,, Stems 2 ft.	Anthers emerged	3·79	41·59
Long grass	*Panicum maximum*, type B	2½–3 ft.	No flowering heads	3·83	35·42
	Pennesetum purpureum	2½–3 ,,	,, ,,	4·86	35·17
	Cynodon plectostachyum	2 ,,	All stages of maturity	8·14	34·96
	Cenchrus ciliaris, type D (2nd growth)	2½–3 ,,	Early flowering	8·23	49·19
	,, ,, type B (2nd ,,)	2½–3 ,,	,, ,,	5·60	48·30
Long fodder grass	*Panicum maximum*	Leaves 4 ft. Stems 6 ,,	Early flowering	2·74	29·21
	Pennesetum purpureum	Up to 8 ,,	Anthers emerged	3·55	27·66

Table 1 gives the composition and average digestibility coefficients of the different species examined, and Table 2 gives the digestible-protein and starch-equivalent values together with the height and stage of maturity of the samples.

These Tanganyikan grass samples are richer in fibre than English pasturage and, with the exception of star grass (*Cynodon plectostachyum*) at 1 ft. high, are poorer in crude protein. The contents of soluble ash are satisfactory, and proportions of lime, phosphate, potash, soda, and chlorides are normal.

Star grass, which has proved its value as a grazing and hay crop, was used as the standard of comparison. Unfortunately, when this series commenced, the high feeding-value of African foxtail (*Cenchrus ciliaris*) was not realized, and this grass was not included in the short-grass group. The imported *Digitaria Pentzii* and the wet-area *Leerzia hexandra* are of inferior composition to young star grass. In the group of medium-length grasses, star grass has much less crude protein and is equalled by African foxtail grass. The composition of fodder grasses (*Panicum maximum* and *Pennesetum purpureum*) and that of the first growth of Rhodes grass (*Chloris gayana*) are nearly as good as that of star grass, but the second growth of Rhodes grass and the other species are poorer in protein and richer in fibre than star grass. In the long-grass group, African foxtail, type D, has a better composition than type B, and has the same crude protein-content as star grass but is a little more fibrous. The fodder grasses have slightly lower protein-contents than star grass. In the fourth group, where the fodder grasses have reached the flowering-stage, a considerable falling off in their composition is observed.

The digestibility coefficients of these Tanganyika grasses are lower than those found for closely grazed grasses in England, and just as composition falls off with advancing maturity so also does digestibility value. In the short-grass group, star grass is more digestible than *Leerzia hexandra* or *Digitaria Pentzii* of the same height, but the latter species when 4–6 in. and 6–9 in. high is more digestible than star grass 8–12 in. high. In the medium-length group, star grass had a lower digestibility than the other species examined, whilst African foxtail, *Paspalum dilatatum*, and first-cut Rhodes grass are the best. In the long-grass group, star grass again has a lower digestibility coefficient than both types of African foxtail grasses, and is intermediate between the values recorded for the fodder grass when 3 ft. high and at the flowering-stage.

Somewhat erratic values are recorded for the ether-soluble matter, and rather low coefficients are found for crude protein in some cases. As in other experiments with East African grasses [1], the crude fibre is often as efficiently or more efficiently digested than the soluble carbohydrates.

It is necessary to point out that the star grass examined was a mixture of types D and E. It has been shown [2] that these two types are poorer in crude protein than most other types of star grass, and in grazing tests [3] it has been proved that type E is inferior to the other types. The better star-grass types (particularly the *Same* and C types) would almost certainly have given better results.

From the figures in Table 2 it is seen that in the short-grass stage, star grass is the best of the species examined. When 4–6 in. high, *Digitaria Pentzii* has a good feeding-value, but when at the same height as the star grass it is definitely inferior. *Leerzia hexandra* has less than half the digestible protein-content of star grass. Even in the short-grass stage, it is seen that the Tanganyika species have poorer feeding-values than English pasture-grasses.

Of the medium-length grasses *Cenchrus ciliaris*, type D, is the best because, though at a more advanced stage of maturity than star grass, it has the same digestible-protein content and a higher starch-equivalent value. The first growth of Rhodes grass is of high energy value but its second growth is much poorer. The fodder grasses *Panicum maximum* and *Pennesetum purpureum* are nearly as good as the first growth of Rhodes grass but are not of such good feeding-value as African foxtail. Star grass possesses a poor starch-equivalent value, which is no better than that of second-growth Rhodes grass. Both samples of *Paspalum dilatatum* had high starch-equivalent values but contained small quantities of digestible protein (less than half that in star and African foxtail grasses). *Andropogon caricosus* was the poorest grass examined but it was also the most advanced in maturity.

In the long-grass group, *Cenchrus ciliaris*, type D, is the best. Type B has a lower digestible-protein value. It is interesting to note that at this taller stage, type D has as high a feeding-value as the smaller though equally mature sample in the short-grass group. Star grass again shows the same digestible-protein content as type D African foxtail but has a much lower starch-equivalent value. The fodder grasses are lower in digestible protein than star grass but have the same energy value.

The fodder grasses at flowering have much lower feeding-values than when cut at $2\frac{1}{2}$–3 ft. high.

It is interesting to compare these figures with the results of grazing tests. Staples [3] states that 'Star grass, type C, appears to be the most satisfactory of the permanent-pasture species so far tested, but the more recently established African foxtail, type D, offers considerable promise and has the advantage that it can be readily established from seed'. His figures indicate that star grass, type C, is superior to types D and E, a mixture of which was used in these trials. African foxtail was included only for the last two years of the grazing tests but it surpassed all grasses other than the fodder grasses. Staples had to discard Rhodes grass from Australian seed as it failed to establish itself properly and poor yields were obtained. *Andropogon caricosus* and *Digitaria Pentzii* gave poor returns and were discarded. The fodder grasses, used for combined soiling and grazing, gave very good results.

The grazing tests and the digestibility trials give similar results as far as they go, but the grazing tests also reflect the yield per acre and the ability to withstand grazing.

Summary

(1) *Cenchrus ciliaris*, type D, can be regarded as the best grass examined at Mpwapwa. It is superior to a mixture of the poorer types of star grass,

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but it was not determined whether it would contain as much digestible protein in the short-grass stage as the better types of star grass.

(2) An indigenous type of *Chloris gayana* possesses a high feeding-value for the first growth of grass, but the second growth of the season is very much poorer.

(3) The indigenous wet-area grass *Leerzia hexandra* does not give the yield nor have the same feeding-value as star grass.

(4) The imported grasses *Paspalum dilatatum*, *Digitaria Pentzii*, and *Andropogon caricosus* have neither equalled nor surpassed the better indigenous species. Under dry conditions they do not yield so well.

(5) The fodder grasses *Panicum maximum* and *Pennesetum purpureum* have practically the same feeding-value at all stages of maturity under dry conditions. As their feeding-value drops considerably after they reach 3 ft. in height, they should be cut not later than at this height.

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CROP RESPONSE TO INTER-ROW TILLAGE[1]

H. C. PEREIRA

(*Rothamsted Experimental Station, Harpenden, England*)

Is the purpose of intertillage of wide-spaced crops solely to control weeds or has the mulch, which is produced as a by-product of the weed-destruction, any beneficial effect on the crop? It is generally agreed that the fundamental purpose of intertillage is weed-control, but there is a firm belief in practical farming circles that the mulch produced by the hoeings is of itself of great benefit. The purpose of this paper is to examine the available data to decide if mulching, *per se*, has this supposed beneficial effect on the crop, for if it has not, then it will be worth while investigating if the mulch-producing methods of hoeing and grubbing are the most economical or efficient way of weed-control. In particular, a scraper or soil-sweep that only disturbs the top inch of soil without producing any appreciable surface mulch might be a more efficient and economical way of weed-control than the deeper cultivation that is done by hoes or grubbers. Agricultural experiment stations in the U.S.A. have published, during the last half-century, a formidable volume of literature on the subject. Much of the early work included little or no replication, but the contrast between soil scraped to destroy weeds and soil stirred with implements has been a common factor in a large number of the experiments. These have included widely differing conditions of soil and climate. This range of conditions is highly desirable in testing any question in the field, and valuable information may be obtained from a survey of the published results of this series of simple plot trials.

1. *Experiments with Maize in the U.S.A.*

This evidence has for long been considered inapplicable to British agriculture, since most of the trials were conducted with maize (field corn), a crop grown in rows about 3–4 ft. apart and of no economic importance in Britain. Also the Great Plains, where much of the early work was done, have extremes of climate which are rare in British experience. It is, however, under occasional drought conditions in Britain that 'dry farming', i.e. inter-row tillage aimed at moisture-conservation, is most strongly advocated. This evidence cannot be ignored entirely. Further, as the tillage methods for maize are used for other crops too, the evidence cannot be completely disregarded, and is therefore surveyed here.

Only those experiments of the most adequate duration, and in some cases replication, are included in Table 1. (The letters in the right-hand column refer to the subsequent commentary.)

Notes on Table 1.—(*a*) This is probably the first record by an experiment station of a field study of the inter-row tillage of crops. Root-

[1] Abridged from a Thesis approved for the Ph.D. degree by the University of London.

studies were attempted and much root-damage by cultivation implements was reported. Sturtevant,[1] in setting out his results, commented: 'Strangely enough, we have . . . been unable to obtain decisive evidence in favour of cultivation.'

(*b*), (*c*), and (*d*) This unexpected failure of inter-row tillage to produce effective increases in crop yield was observed at other experiment stations, over a course of several years of simple plot trials.

TABLE 1. *The Effect of Intertillage compared with Weeding on the Yield of Maize*

Experiments with field corn			*Results: Grain Yield in Bu./Acre*				
Year of publication	*Experiment Station*	*Duration in years*	(i) *Weeded no intertillage*	(ii) *Normal intertillage*	(iii) *Extra deep or frequent intertillage*	*Per cent. increase for* (ii) *over* (i)	
1887	Geneva, N.Y.[1]	4	70·5	56·8	..	−36·0	(*a*)
1897	Illinois Unis.[2]	7	69·1	70·79	..	+ 2·4	(*b*)
1900	Utah[3]	5	64·03	60·15	62·12	− 6·0	(*c*)
1900	South Carolina[4]	2	62·00	62·95	..	+ 1·5	(*d*)
1912	*28 States*[5]	7	99·1%	100%	..	− 0·9	(*e*)
1915	Minnesota[6]	3	64·17	49·15	62·71	−23·4	(*f*)
1915	Illinois[7]	8	45·9	39·2	..	−14·6	(*g*)
1917	Virginia[8]	4	49·0	59·4	58·6	+21·3	(*h*)
1918	Kansas[9]	4	38·6	40·4	38·2	+ 4·7	(*i*)
1925	Illinois[10]	6	54·5	55·6	55·3	+ 2·1	(*j*)
1925	Arkansas[11]	19	36·3	38·6	36·7	+ 6·3	(*k*)

Mean percentage increase for cultivations −3·8.

(*e*) As a result of the above evidence the U.S. Department of Agriculture organized a standardized trial, over a wide range of both soil and climatic conditions. On two 80-yard 5-row plots the mere removing of weeds by scraping was compared with the supposedly ideal cultivations. No weeds were allowed to grow on either plot. The results were summarized by Cates and Cox[5] in 1912. Although the scraping treatment produced some apparently unfavourable conditions, such as soil surfaces 'dry and hard as a floor', there was a difference of less than 1 per

[1] Geneva (N.Y.) Agric. Expt. Stat., *Ann. Rept.* 5, 1886, 46.
[2] Ill. Univ. Agric. Expt. Stat., 1892–6, *Bull. Nos.* 20, 25, 31, 46.
[3] Utah Agric. Expt. Stat., 1900, *Bull. No.* 66.
[4] S. Carolina Agric. Expt. Stat., 1900, *Bull. No.* 61.
[5] U.S. Dept. Agric. Bur. Plant Ind., 1912, *Bull. No.* 257.
[6] Univ. Minn. Agric. Expt. Stat., 1915, *Bull. No.* 149, Part I.
[7] Ill. Agric. Expt. Stat., 1915, *Bull. No.* 181.
[8] Virginia Agric. Expt. Stat., 1917, *Bull. No.* 214.
[9] *J. Amer. Soc. Agron.*, 1917, **9**, 49.
[10] Ill. Univ. Agric. Expt. Stat., 1925, *Bull. No.* 259.
[11] Univ. Ark. Agric. Expt. Stat., 1927, *Bull. No.* 219.

cent. in the grain-yield means for the 112 experiments. These had been conducted in 28 States, in widely varying soils and climates:

	Grain		*Fodder*	
Year	*Number of experiments*	*Average yield of scraped, as percentage of cultivated plots*	*Number of experiments*	*Average yield of scraped, as percentage of cultivated plots*
1905+6	5	108·4	3	96·36
1907	8	110·84	2	91·6
1908	6	97·93	4	94·95
1909	25	105·27	10	101·15
1910	43	96·51	19	96·19
1911	25	92·37	15	91·24
Weighted means	(112 expts.)	99·108	(53 expts.)	95·1

The importance of these experiments lies in the wide range of soil types involved. These varied from 'fine sandy soil' to 'stiff yellow clay', and the sites ranged from the coast to the central plains. As the data gave a distribution-curve of normal type, Cates and Cox inferred that the results were probably reliable. Rainfall had little effect. The soil mulch appeared to be equally unremunerative on fertile and on infertile soils, for the ratio of unmulched to mulched crops was 97·19 per cent. for all grain yields below 30 bushels, and 98·34 per cent. for all yields above 50 bushels per acre. The results were interpreted as showing no important effect from soil mulching beyond that of weed-destruction. Mosier and Gustafson,[1] studying these results, raised a point of great interest three years later by showing that the mulch appeared to affect the yield favourably on heavy soils, but unfavourably on light soils.

(*f*) and (*h*) represent the results of more detailed studies in continuation of those summarized in (*e*). They show approximately equal and opposite effects of normal inter-row tillage, but both show negative results for more deep or frequent soil stirring.

(*g*) Mosier and Gustafson[1] included a study of weed-competition. They irrigated some weedy plots, but this only partially remedied the weed-damage, showing that factors other than soil moisture were important in weed-competition.

(*i*) Call and Sewell[2] concluded that weed-destruction was the major purpose of inter-row cultivation.

(*j*) Wimer and Harland[3] continued for six years the work of Mosier and Gustafson, and compared both medium and shallow inter-row tillage with scraping. They concluded that on their silt-loam soil such tillage should be shallow, and given only for weed-destruction.

[1] Ill. Agric. Expt. Stat., 1915, *Bull. No.* 181.
[2] *J. Amer. Soc. Agron.*, 1917, **9**, 49.
[3] Ill. Univ. Agric. Expt. Stat., 1925, *Bull. No.* 259.

(*k*) Nelson and McClelland[1] summarized in 1927 the results of nineteen years' continuous trials of a simple pattern in which only the controls were replicated. They reported an average loss of 81 per cent. of the crop when weeds were not destroyed, whilst the five different cultivation treatments produced average variations of less than 6·5 per cent. Experiments on heavier soils by Sachs[2] were inconclusive, duplicated control plots varying by over 100 per cent. in each of the four years.

The experimental data, summarized above, illustrate a great many cases where inter-row tillage beyond that essential for weed-destruction has given no remunerative return, which is particularly emphasized by column (iii) in Table 1. These experiments justify the conclusion that, for the maize crop, inter-row cultivations beyond those necessary to keep the crop clean are unlikely to produce positive economic returns except in special circumstances. This failure of an important American crop to respond to the traditional methods of inter-row tillage is a challenge to the hypotheses on which this tillage is advocated.

2. *Experiments with Vegetable Crops in the U.S.A.*

Thompson,[3] of Cornell University, N.Y., published in 1927 the results of six years of well-replicated plot experiments on the inter-row tillage of vegetables growing in a sandy loam soil. Surface-scraping was compared with the maintenance of a mulch by weekly hand-stirring of the soil. He studied and photographed the root-systems of six vegetables, in search of a relation between the character of the root-system and the response of the crop to mulching cultivations.

Carrots, cabbages, and tomatoes showed no significant increases in yield when mulched, but significant increases were obtained for beet (4·25 per cent.), onions (7·6 per cent.), and celery (24·1 per cent.). Only with celery were the increases consistent. With both the beet and onions larger yields were produced in some years on the scraped plots. Weed-competition on some extra plots caused heavy losses. Thompson concluded: 'The yield-data show conclusively that weed-control was of much greater importance than the maintenance of a soil mulch.'

His root-studies on beet revealed a lateral root-spread of 3–4 in. when the plants were 6 in. high. At a height of 12 in., when the diameter of the young beet was about 1 in., the soil between the rows was filled with fine roots to a depth of 4 in. Throughout the growth of the plants, root-development was at a maximum in the first 3 or 4 in. of the soil. Thompson concluded that for beet, 'cultivation with ordinary implements would cause considerable injury at any time after the first few weeks'. The root-systems of the vegetables partly explained their response to inter-row tillage. His results for beet are given above in some detail, because vegetables of a similar type form a large part of the British 'root-break'. Cultivation of such vegetables is evidently liable to produce considerable root-damage in the middle part of the growing-season. This damage is not visible from the surface, and is not easily detected.

[1] Ark. Univ. Agric. Expt. Stat., 1927, *Bull. No.* 219.
[2] Ark. Univ. Agric. Expt. Stat., 1926, *Bull. No.* 205.
[3] Cornell Univ. Agric. Expt. Stat., 1927, *Mem. No.* 107.

In 1923 the experiments were extended to a contrasting soil type. Thompson, Wessels, and Mills[1] published in 1931 the results of the second series of experiments on a silt loam on Long Island (N.Y.). Their results for the potato crop are discussed in section 4 below. Five years of experiments with carrots, four with cabbages, onions, and potatoes, and seven with beet and tomatoes, all on this heavy soil, led them to the conclusion that 'the main advantage derived from inter-row cultivation was due to weed-control, and that the formation and maintenance of a soil mulch did not significantly increase the yield of any one of the six crops'.

In 1938 leading members[2] of the U.S. Department of Agriculture summed up the experience of the Department in the following generalizations: 'Tillage of growing crops is now regarded primarily as a means of weed-control, as it is becoming better recognized that the chief purpose of cultivation is to destroy weeds, not to create a mulch.' With specific reference to the potato crop they consider this to need 'some ridging to protect the tubers, although, in general, level cultivation is preferable to ridging which involves deep tillage and root pruning. The labour of inter-tillage, and the total tillage costs, may be reduced by cultivations before the crop is planted.'

3. *Experiments with Roots and Kale in Great Britain*

As yet very little experimental work on inter-row tillage has been carried out in Britain. Interesting results, which were not published, were obtained in 1907 and 1908 at Reading, when the effects of weed-competition and hand-hoeing were studied for the mangold crop. After applying 10 tons per acre of dung and 7 cwt. per acre of fertilizer in each year, the results from an area of half an acre were:

Treatment	*Yield in tons per acre*	
	1907	1908
9 rows. No weeding after setting out of plants . .	15¾	16¾
10 rows. Hoed once only	33½	30¼
10 rows. Hoed twice only	37⅞	36¾
10 rows. Kept completely clean by several hoeings . .	39½	38
9 rows. Kept clean by hand-weeding only, no hoeing .	40	38¼

A single hoeing appeared nearly to double the crop, a second hoeing to add another 5 or 6 tons, whilst frequent hoeings appeared to produce little more than 1 ton further increase. The rows kept clean by hand-weeding surpassed the remaining rows in both years, suggesting strongly that the benefit of the hoeing lay in the killing of weeds rather than in the improvement of soil texture. The consistency of the results for the two years indicates that they are probably reliable, although the lack of statistical design renders impossible any accurate estimate of experimental error.

The first British field studies of inter-row cultivation to be conducted

[1] Cornell Univ. Agric. Expt. Stat., 1931, *Bull. No.* 521.

[2] U.S. Dept. Agric., *Yearbook*, 1938, p. 321.

with statistically controlled designs were laid down at Rothamsted Experimental Station in 1932 and have been described by Keen and Russell.[1] Trials were carried out with kale and sugar-beet on the heavy Rothamsted soil, and with sugar-beet on the sandy soil of the Woburn Experimental Farm. No economic advantage was obtained from intensive hoeing in any one of the five experiments, and in three of the five this extra work both increased growing-costs and reduced yields. These English results are in accord with the American ones, but they contrast sharply with the widely held traditional views on the value of stirring the soil while such crops are growing. Naturally, a large series of experiments will be needed before the influence of seasonal and other factors can be fully defined, and occasional conflicting results may be expected, especially on light land.

4. *Inter-Row Tillage for the Potato Crop*

In their large amount of field work on tillage the numerous agricultural experiment stations seem to have overlooked the potato crop until quite recently, although Sturtevant[2] in 1882, working at Geneva, N.Y., showed that ridging gave no advantage over flat culture on a 'rather wet clay soil'. He further studied the root-system of potato plants grown under different systems of cultivation and concluded that 'for the potato plant a system of cultivation which interferes with the root-system is a disadvantage'. The U.S. Department of Agriculture in 1921 wrote: 'The objects of tillage are to prevent weed-growth, conserve moisture, aerate the soil, increase the available supply of plant-food, and stimulate root-growth.'[3]

The experiments of Thompson, Wessels, and Mills[4] on inter-row tillage covered the four years 1927–30; they were done in Long Island, N.Y., on a well-manured silt loam, with gravel at 3–4 ft. The three tillage treatments were: (1) scraping with a sharp hoe; (2) shallow cultivation with a 'garden tractor' 4 to 6 times; (3) shallow cultivation 8 to 9 times. There were three replications and all weeds were eliminated from all plots. The potatoes were not earthed up. The mean results for the four years were:

Cultivation treatment . . .	(1)	(2)	(3)	*Weedy plot*
Total yields in lb. per plot . . .	158·82	150·42	148·35	52·67

The yields of the scraped plots (1) were significantly greater than those of (2) or (3), and this effect was consistent, e.g., of the twelve comparisons provided by three replications in four years, eleven favoured the scraping treatment. The rainfall in the district varied from 26·7 to 30 in. in the four years.

They concluded 'that maintenance of a soil mulch by cultivation was

[1] *J. Roy. Agric. Soc.*, 1937, **98**, 53.
[2] Geneva (N.Y.) Agric. Expt. Stat., *Ann. Rept.*, 1882.
[3] U.S. Dept. Agric., Bur. Plant Ind., 1921, *Farmers' Bull. No.* 1190.
[4] Cornell Univ. Agric. Expt. Stat., 1931, *Bull. No.* 521.

of no value, or else that the cultivation was injurious, and offset any advantage that might have been derived from the mulch'. They reported much greening of tubers, and therefore suggested that ridging was necessary, but it should be moderate, so that cultivation could be kept as shallow as possible. The soil type and the total precipitation in these experiments are similar to those occurring in parts of Britain, and the results should, therefore, be applicable to some British conditions.

Merkle and Irvin,[1] in 1931, published results of five years' work in Pennsylvania on the inter-row tillage of various vegetable crops, including potatoes. They worked on a heavy silt loam, well drained, with no water-table within measurable depth. Their three cultivation treatments were: (1) scraping with a sharp hoe, (2) three cultivations 2–3 in. deep, (3) six to eight similar cultivations. The treatments were replicated 2, 6, 4, 4, and 3 times respectively in the five years of the experiment. Only in the one exceptionally dry season of 1930 (half the normal rainfall) did the cultivation treatments produce any significant result. Treatment 3 then showed some advantage both in yield and in moisture-content. Merkle and Irvin concluded: 'The results reported here do not discourage any practice which will keep weeds under control. They do show, however, that when weeds are kept under control further cultivation of potatoes for other purposes is not essential.'

The publication of Thompson's results in 1927,[2] already described, led to the conducting of field trials in Maine (one of the leading potato-producing States of the U.S.A.) by the U.S. Department of Agriculture, in 1931–3. Lombard[3] reported the results in 1936. Four replications were used. Three-year-means for yield are given below.

Treatment	*Total yield bu./acre*	*Percentage of ware*
1. Harrowing (2 weeks after planting), one grubbing and one early high ridging	365·6	92·4
2. Harrowing, five grubbings, moderate ridging	360·3	92·2
3. No harrowing, two grubbings, moderate ridging	364·0	92·0
4. No harrowing, three grubbings, moderate ridging	351·0	91·7
5. No harrowing, four grubbings, moderate ridging	360·8	93·0

All weeds were removed by the hand-hoe. None of the differences was statistically significant, and the comparison of treatments 1 and 2 shows that the four additional grubbings received by 2 did not improve the yield. The soil type is not mentioned in the report. Lombard concluded that weed-control was the only important effect of inter-row cultivation.

Results of a very extensive study of tillage methods for potatoes were published by Moore,[4] of Cornell University, in 1937. He reported trials

[1] Penn. Agric. Expt. Stat., 1931, *Bull. No.* 272.
[2] Cornell Univ. Agric. Expt. Stat., 1927, *Mem. No.* 107.
[3] *Amer. Potato J.*, 1936, **13**, no. 9.
[4] Cornell Univ. Agric. Expt. Stat., 1937, *Bull. No.* 662.

of (1) level culture, (2) 4-in. ridging, (3) 7-in. ridging, all duplicated for the comparison of (*a*) scraping with a sharp hoe, (*b*) cultivation with a one-horse grubber, working at a depth of 3–4 in. every 10 days until the blossoming of the plants. The experiment included the three growing-seasons of 1932–3–4. Four replications of 30-yard three-row plots were employed, the row distance being 36 in. The soil is described as a well-drained very heavy silt loam.

Elaborate studies of the root-development were made at all stages of the plant-growth, and the effect on the roots of inter-row grubbing was clearly shown. Moore found that 'at the age when the tops are only 6 in. to 8 in. tall, the lateral spread is sufficient to be subjected to severe pruning by cultivation'. He investigated the possibility that the pruning of lateral roots by tillage might result in the deeper penetration of the remaining roots. He found that when the roots 4 in. from the row were pruned to a depth of 4 in., the remaining roots reached a depth of 29 in., whilst the roots of unpruned plants reached 33 in. He observed that the potato roots recovered fairly rapidly after such pruning, to re-establish themselves in the rich surface soil. Thus 24 days after cultivation had ceased he found that 'mid-way between the 36-in. rows the surface soil for the first 6 in. was filled with fibrous roots, the upper half of which were branches of roots pruned by cultivation'. (Roots in the scraped plots filled the entire surface 6 in. of soil, whether level or ridged.) The only difference then visible between roots on scraped and grubbed plots was that 'under cultivation the roots between the rows in the upper 3 in. of soil were almost entirely branches arising from the pruned roots'.

The yields were greatest with level culture, decreasing with increasing height of ridge. This Moore attributed mainly to the decrease in the moisture-content of the first 12 in. of soil with increasing height of ridge. A very high correlation was observed between yield and moisture-content. Grubbing appeared to have no effect on yield when the potatoes were grown in ridges, but there was a suggestion that it reduced the yield on the level culture. He found that protection of the tubers from greening was satisfactory when broad ridges only 2 in. high were made. Moore concludes that 'deep cultivation at any time, except possibly before the plants are 2–4 in. high, cannot be justified from the evidence here presented. Any stirring of the soil that exceeds 1 in. in depth is accompanied generally by a certain amount of root-pruning.'

Lähde,[1] of Finland, in 1938, described some experiments comparing ridging with flat culture, and showed that:

(i) Whenever the grubber or horse-hoe is used within 30–35 cm. of the plants in the later stages of plant-growth, some root-damage is done, which increases as the implement works nearer to the plants.

(ii) The lateral spread of the tuber-bearing stolons was found to vary greatly in different Scandinavian varieties of potatoes. He gives photographs of the washed root, tuber, and stolon systems. In the varieties with the greater lateral spreading of stolons, the use of inter-row tillage implements in the later stages of plant-growth causes damage to the stolons resulting in reduced yields. A 7-year series of trials at the Agri-

[1] *Valt. Maatalousk Julk.* (Helsinski), 1938, no. 98.

cultural Experiment Station at Tikkurila (Finland), on sandy soil, showed mean yield increases of 7·5–9 per cent. over the uncultivated controls, by a single early earthing-up. This increase was reduced by a second earthing-up, and completely negatived by a third such operation. Deep inter-row tillage, in the early stages of plant-growth, with a 'Pelturi' grubber, gave slight decreases in yield on sandy soil, but slight increases on clay soil. No significant effects of tillage were detected in the starch-content of the tubers. Lähde also quotes experiments at the Piikkio Station in 1931 and 1932, on a sandy soil, comparing flat culture with ridging, and other trials in 1934–6, on both clay and sandy soils at Nordhame, comparing ridging, superficial hoeing, and deep grubbing. The results of both series showed no differences greater than the experimental error. A single year's experiment at Süd-Pohjanmaa, on a clay soil in 1933, gave results distinctly favouring earthing-up once, at an early stage of plant-growth, as compared with horse-hoeing four times, earthing-up four times, or a combined treatment. Several more examples, giving similar results, are described.

Lähde concludes that ridging and level culture have given, on the average, equal yields. He prefers, however, ridged to level culture for practical reasons, since it reduces greening of tubers and, in his opinion, facilitates weed-destruction and harvesting. The ridging must, however, be done early, when the plants are 10–20 in. high, and only one such ridging should be given. If weed-growth makes a second ridging necessary, this must be given before the plants bloom.

Apart from scientifically planned trials, useful evidence may be gathered from the records of Growers' Clubs, membership of which is restricted to those growers whose crop yields attain a definite minimum standard. Dickey, in 1935,[1] gave an account of the '400 Bushel Club' of Pennsylvania, which had then been meeting for seven years. He showed that in spite of environmental difficulties the methods of the most successful growers had tended towards standardization: 'The average number of inter-row cultivations has decreased from 3–5 in 1923 to 2–3 in recent years. Growers are coming to a better realization of the theory of cultivation, and its possibilities and dangers, and are making much greater use of the harrow before emergence of the crop, and of the weeder (an instrument bearing light spring-tines of a type similar to those of a hay-rake, several of which operate between each row). The percentage using a weeder has risen to approximately 90.' This type of evidence has a ready appeal to the practical farmer, and similar organizations for potato growers elsewhere would serve a very valuable purpose.

The first data on inter-row tillage of potatoes to be obtained in England were published in the Rothamsted Report for 1932, when Mr. H. Stewart gave the results of a randomized-block experiment carried out at Kingennie, Angus. On a medium loam four randomized blocks, of eight plots each, were laid down to include four levels of application of ammonium sulphate, with two levels of intensity of cultivation. A heavy crop was obtained (an average of 14·13 tons per acre of the Kerr's Pink variety), but no improvement in yield resulted from the additional inter-

[1] *Amer. Potato J.*, 1935, no. 12.

row working. Expressed as percentages of the general mean, the treatment yields were:

Ammonium sulphate cwt./acre	0	1	2	3	*Mean*
Normal cultivation . . .	98·6	100·1	100·3	102·9	100·5
Intensive cultivation . . .	93·6	97·4	103·4	103·6	99·5
Intensive – Normal . . .	−5·0	−2·7	3·1	0·7	−1·0

Thus the additional cultivations, which included an extra early earthing-up and a deeper grubbing, produced apparent small decreases for low dressings of sulphate of ammonia, but smaller increases for the heavy dressings. In spite of the exceptionally low standard error (1·8 per cent. of the mean yield per treatment as compared with an average of 7·5 per cent. for potato trials at Rothamsted[1]), none of these yield differences for the cultivation comparisons reached the 5 per cent. level of statistical significance. The response to the sulphate of ammonia was, however, significant.

The British practices of inter-row tillage for potatoes have been influenced by a number of beliefs for which there is little or no scientific evidence. The several well-replicated field trials, described above, have established that under certain conditions in the U.S.A. the inter-row tillage of potatoes should be as shallow and as infrequent as possible: the limiting aims of such tillage should be the thorough destruction of weeds and the protection of the tubers by a moderate covering of earth. In America the workers have emphasized the root-damage to the potato plants which arises through stirring the soil more deeply or more frequently than necessary. The unexpected results of cultivation studies at Rothamsted and Cambridge and, in particular, the results of the Rothamsted studies of inter-row tillage in sugar-beet and kale, emphasize the possibility that the British potato crop also may not respond to such operations in the manner assumed by tradition. The only British data, a single year's results of an experiment in Scotland, show no response by potatoes to intensive cultivation.

5. *The Ottershaw Park Experiments on the Inter-row Tillage of Potatoes*

The author laid down at Ottershaw Park, Surrey, experiments covering the years 1937–9, inclusive, in order to obtain quantitative data on the response of main-crop potatoes to inter-row tillage for a light soil under British conditions. The experiments are only briefly summarized here, as a full description is given elsewhere.[2]

The hypotheses on which information was sought were: (*a*) that soil-stirring between plant rows is of direct benefit to the potato crop, in addition to its essential purpose of destroying weeds; (*b*) that the ridging-up of the plants is beneficial in addition to its main object of protecting the tubers from exposure to light and vermin.

[1] *School Science Review*, 1937, no. 74, 262. [2] *J. Agric. Sci.*, 1941, **31**.

These hypotheses were tested by three years of replicated plot experiments with main-crop potatoes, on a light sandy loam with a sand and gravel subsoil. Three principal treatments were compared:

(N) ridging-up to a height of 6 in. with two preliminary grubbings;
(F) from two to four preliminary grubbings in addition to the cultivations for (N);
(U) or (S) control plots on which the soil was unstirred and the weeds were completely eliminated by surface scraping or hand-picking.

The three growing-seasons included spells of wet and of very dry weather, the rainfall varying from 18 to 30 in., and a sloping water-table maintained a continuous supply to at least one complete replication, while becoming too deep to affect the remainder. Under at least some of these varying conditions, these hypothetical benefits of ridging and grubbing, if they are real, should have become apparent. The mean yields for the three principal treatments are given in Table 2.

TABLE 2. *The Effect of Inter-Row Cultivation on Crop Yields*

Annual mean yields in tons per acre

Treatment	*F*	*N*	*U or (S)*	*Standard error*	*(F–U)*	*(F–U)% of U*
Number of cultivations	4–6	2	0			
1937	12·36	10·37*	12·33	± 0·595	+ 0·03	+ 0·24%
1938	8·82	8·80	8·63	± 0·32	+ 0·19	+ 2·20%
1939	10·75	10·99	11·79	± 0·499	−1·04	−8·82%
3-yr. mean	10·64	10·05	10·92		−0·28	−2·56%

* All plots considered in this table, except N of 1937, were weed-free.

The results do not support the hypothesis (*a*) set out above. The experiments of 1937 and 1938 were each replicated six times, and that of 1939 four times. Of the sixteen comparisons thus provided between the intensive (F) cultivations and the unstirred (U) or (S) controls, ten resulted in favour of the control treatment.

The percentage of ware potatoes (over the 1½ in. riddle) was found for every plot in each of the three trials. It was not very variable and the trials were capable of detecting an effect of from 1 to 3 per cent. of the mean value. No result smaller than this would in any case be of much economic importance. The result of the experiments was that the percentage of ware was not affected by the cultivation treatments, provided weeds were absent. If the cultivations had proved beneficial to the plants, an increase in the proportion of large tubers could be confidently expected. That no such increase occurred in the three years is therefore further evidence against the original hypothesis.

Comparisons also carried out in one or more seasons included depth of grubbing; earliness of grubbing relative to the growth stage of the plant; effect of fertilizer-placing; and the effect of limited weed-competition when weeds were controlled only by the two cultivations of the

(N) treatment. Depth of grubbing had no apparent effect, and the times of grubbing little effect, either on the total yield or on the size of the tubers. A beneficial effect of placing of fertilizer in the bouts, as compared with harrowing it in on the flat, was strongly indicated, but was not conclusively demonstrated by the experiment. This fertilizer-placing significantly reduced the proportion of the ware potatoes spoiled by greening on the scraped control plots.

When the crop was cleaned only once before the final grubbing and ridging-up, weeds caused significant decreases in yield and in percentage of ware.

The potato crop in the Ottershaw experiments proved to be unexpectedly insensitive to inter-row tillage treatments. It is perhaps surprising that when in 1938 the intensive treatment was deliberately given over two weeks later, thereby inevitably causing additional root-pruning at a stage when the root-spread had reached the row centres, no very important reduction in yield was observed. Throughout the trials the crop seemed to be remarkably adaptable, and to be able to grow well under a wide variety of cultural practices.

The trials lay within the range of normal conditions under which potatoes are grown commercially on light land. Hence if the hypothetical benefits of inter-row cultivation are of general economic importance, they should have produced, in at least some part of the trials, positive yield increases more than sufficient to cover the cost of the additional cultivations. No such increases were in fact evident.

Only moderate dressings of dung and fertilizer were used; the plot yields were, however, good, all three being above the averages published annually for the British main-crop. This is important, since it shows that a high standard of yield may be maintained on light land, without deep or frequent soil stirring.

6. *Discussion on the Inter-row Tillage of Potatoes*

The mere demonstration of the ineffectiveness of intensive inter-row cultivation to increase the potato yield need not condemn these methods in actual farming practice. The practical grower could raise three further points requiring an answer before these extra cultivations can be profitably omitted, namely, (*a*) Is frequent grubbing and ridging-up the easiest way of keeping the land clean? (*b*) Do these extra cultivations give any indirect economic return by reducing the time spent on spraying and harvesting? (*c*) Do they benefit the succeeding crops in the rotation?

The unexpected susceptibility of the potato crop to competing weeds is in marked contrast to its lack of sensitivity to cultivation treatments. But it is possible that shallow sweeps or light spring-tine weeders, working to a depth of about 1 in., could replace deeper grubbings on light soils with a consequent appreciable saving of time and fuel.

The fitting of efficient haulm-lifting guards to the tractor and sprayer wheels, such as are already used with success in crops of laid corn, may prove a less expensive way of facilitating spraying than ridging-up.

The problem of harvesting appears to vary considerably with soil type.

The potato-lifting plough, fitted with a double set of lifting fingers, was used successfully for harvesting unridged guard-rows at Ottershaw Park, and this implement is much used in South Lincolnshire. The spinner undoubtedly works more easily with fairly high ridges, especially on heavy soils. The power-operated chain-elevator digger, a potato-harvesting implement used almost exclusively in some potato-growing areas of the U.S.A., appears particularly suited to modern tractor-cultivators. It is little known in England, but Hardenburg,[1] in observations on 254 fields of potatoes near New York, reports it to be capable of lifting crops ridged 2 in. high with only a little more damage than when the ridges were much higher. It may be possible to adapt the spinner to work with very low ridges on light soils, but while agricultural tradition favours high ridging, the majority of digging implements will continue to be designed for such conditions. In answer to point (*b*), therefore, if the potatoes are harvested by a lifting-plough or by a suitably designed digger, very slight ridging will suffice on light soils. It is important, however, that the ridging-up on such soils should be carried out at the minimum height determined by such practical harvesting requirements, and not be made as high as possible in an attempt to benefit the crop. Such misdirected higher ridging involves deeper preparatory grubbing, thereby causing unnecessary expenditure of power, with probably no effect on the crop beyond extra root-pruning.

The answer to point (*c*) must depend on the weed-population. If the potatoes are grown as the cleaning crop in a rotation, then certain perennial weeds may be best destroyed by frequent deep grubbing. Again, however, it is important that the grubbings on light soils be given with the definite object of weed-destruction, and that unproductive work in excess of these requirements be avoided.

These experimental results may prove inapplicable to heavy soils for the following reasons:

(i) It appears probable that on heavy soils a loose mulch may serve a useful purpose by protecting the soil surface from baking into hard clods.

(ii) It may not be possible, on stiff soils, to secure adequate protection for the tubers without cultivation at least 2–3 in. deep.

(iii) Harvesting requirements may make higher ridges desirable. Stiff clay soils are, however, not well suited to potato-growing, as apart from the above considerations it is also difficult to separate the soil from the tubers.

Summary

1. Inter-row tillage of crops has been tested in the U.S.A. by many simple field trials with maize, and by several well-replicated modern trials with market-garden vegetables. The results have shown the maintenance of a soil mulch between plant-rows to be of little importance in the absence of weeds. The experiments emphasized the importance of weed-destruction. British evidence on inter-row tillage is scarce, but the data available confirm the findings of the American workers.

[1] *Amer. Potato J.*, 1934, **11**, 171.

2. Well-replicated American field trials on the inter-row tillage of potatoes have shown that, under the conditions tested, such tillage should be as shallow and as infrequent as is consistent with the thorough destruction of weeds. British data are limited to a single experiment, in which potatoes showed no significant response to inter-row tillage in the absence of weeds. This evidence is in sharp contrast to British farming tradition and practice for the potato crop, and further investigation is clearly necessary.

3. The experiments conducted at Ottershaw Park in the years 1937, 1938, and 1939 showed that for a well-drained sandy loam, under a considerable range of moisture-supply conditions, main-crop potatoes do not respond in the absence of weeds to ridging-up, or to deep or frequent inter-row grubbings, by any increase in yield or in the percentage of ware. The crop showed successful powers of adaptation to a range of contrasting inter-row tillage treatments.

4. The potato crop showed considerable sensitivity to weed-competition. This indicates that it is of great importance to maintain the crop in a weed-free condition.

5. Inter-row tillage operations on this type of soil should therefore be designed to destroy weeds and to provide moderate cover for the tubers. Intensification of such tillage beyond these limits is not of direct benefit to the plants.

6. These results may not be applicable to heavier soil types. It is probable, however, that they would hold good for most sandy loams. The results indicate the desirability of carrying out further experiments on contrasting British soil types, especially in the important potato-growing areas.

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IMPROVING THE QUALITY OF HAY

A. H. LEWIS

(*Jealott's Hill Research Station, Bracknell, Berks.*)

THE average protein-content of meadow hay made in this country is only slightly higher than that quoted in *Rations for Livestock* [1] for poor meadow hay (7·5 per cent.). In 1939 a note [2] was published drawing attention to a preliminary experiment in which the protein-content of meadow hay was increased by 1·6 and 3·0 per cent. by nitrogenous fertilizers supplying 17·4 and 34·7 lb. nitrogen per acre respectively, applied some 10–20 days before mowing. All the extra nitrogen absorbed by the crop was converted into true protein.

The aim of the present paper is to report further results obtained in 1939 and 1940.

Experimental

The fertilizers were broadcast by hand on the plots. In most of the experiments two dates of application were compared, viz. 'very late', meaning 6–10 days before mowing, and 'late', meaning 14–27 days before mowing. All treatments were replicated at least four times. Individual plots were 1/200 acres in area. In several of the experiments the whole area had been dressed by the farmers with a nitrogenous fertilizer some weeks earlier to increase yields.

In the 1938 and 1939 experiments at Jealott's Hill, sulphate of ammonia, nitrate of soda, and nitro-chalk were compared. As there were no significant differences between the effects of these fertilizers on protein-content or yield, average results for the three fertilizers are quoted. The fertilizer used in the other 1939 experiments was nitro-chalk. In 1938 and 1939 nitrogen was applied at 17·4 and 34·7 lb. per acre. In the 1940 experiments sulphate of ammonia was used and the rates of application were 23 and 46 lb. nitrogen per acre.

In 1939 a little rain fell at some centres between the date of applying the nitrogen and the date of mowing, but in 1940 no rain fell at any centre during this period.

In the 1938 and 1939 experiments at Jealott's Hill, the produce was weighed immediately after cutting and representative samples were taken for determinations of dry matter and nitrogen. The same procedure was followed in the 1940 experiments. In the 1939 experiments at centres other than Jealott's Hill the produce was made into hay on the plots. The hay was then sampled for analysis.

All analytical results are expressed as percentages of oven-dry material. Hay contains about 15 per cent. moisture, so the protein-contents should be reduced by about one-seventh to give figures corresponding to hay. The yields per acre should for the same reason be correspondingly increased to give the yields of hay.

Yields of hay.—Yields and protein-contents are given in Table 1. The

nitrogenous fertilizers affected the yield in Expt. 2 only. The yields at this centre were:

	Cwt. of dry matter per acre
No nitrogen	23·3
17·4 lb. N per acre, very late	28·0
34·7 „ „ „	29·8
17·4 „ „ late	33·6
34·7 „ „ „	36·2
Significant difference (P = 0·05)	5·6

The late dressings increased the yield more than did the very late dressings, as would be expected.

Crude-protein content.—The average crude-protein content of the untreated hay was 10·05 per cent. on a dry-matter basis, which corresponds to 8·5 per cent. crude protein in the hay. This is about 1 per cent. higher than the figure quoted by Watson and Ferguson [3] as the average for meadow hay in this country.

The average increases in crude-protein content in the 1938 and 1939 experiments were 1·01 and 1·68 per cent. for applications of 17 and 34 lb. nitrogen per acre. These average increases are less than those found in the preliminary experiment in 1938, but they are, nevertheless, quite important. The results with 34 lb. nitrogen per acre in Expt. 3 appear anomalous and have reduced the average effect of this dressing. The average increases in 1940, which was a very dry season, were 0·98 and 1·94 per cent. for dressings of 23 and 46 lb. nitrogen per acre.

In 1939 there was an apparent tendency for the increase in protein-content to be greater the higher the yield of hay, but in 1940 the increase in protein-content was definitely higher the lower the yield.

Fate of assimilated nitrogen.—The results in Table 2 show that the nitrogen applied had no appreciable effect on the ratio of true to crude protein. The ammonia-content was not affected except to a small extent by sulphate of ammonia in Expts. 4 and 5 at Jealott's Hill. The amide-content was not appreciably affected in any case. Nitrate was increased to a small extent by nitrate of soda when applied very late, at the high rate, in Expts. 4 and 5.

Recovery of nitrogen applied.—The recovery in the hay crop of the nitrogen applied was as follows:

	Per cent. recovery in hay crop of nitrogen applied			
lb. N applied per acre	17	34	23	46
1938 and 1939	31	25	..	..
1940	..	..	24	22

The average recovery of nitrogen applied early in the usual manner to increase the yield of hay is about 30 per cent. Hence, the recovery in the crop of nitrogen applied 10–20 days before cutting was as high as when the nitrogen is applied several weeks earlier.

A further 10 per cent. of the added nitrogen was recovered in the aftermath in Expt. 1.

TABLE 1. *Yields and Protein-contents of Hay after Late Applications of Nitrogen*

	Centre	Late N applied	Very late N applied	Crop cut	Average yield of dry matter. Cwt. per acre	Per cent. crude protein in untreated hay	Increases in per cent. crude-protein content							
							Very late		Late		Means: time of application		Means: rate of application	
							17 lb. N	34 lb. N	17 lb. N	34 lb. N	Very late	Late	17 lb. N	34 lb. N
1938.	1. Jealott's Hill, Berks.	20 May	30 May	9 June	22·9	8·69	1·61	2·87	1·59	3·05	2·24	2·32	1·60	2·96
1939.	2. Bideford, Devon	5 June	13 June	19 June	30·2•	7·94	1·25	1·53	1·19	1·50	1·39	1·35	1·22	1·52
	3. Curry Rivel, Somerset	23 May	31 May	7 ,,	26·0	9·63	0·81	0·25	0·50	0·00	0·53	0·25	0·66	0·13
	4. Jealott's Hill, Berks.	19 ,,	30 ,,	7 ,,	38·3	8·40	1·33	2·25	1·15	1·81	1·79	1·48	1·24	2·03
	5. ,, ,,	13 June	23 June	30 ,,	32·6	7·65	0·87	1·75	1·17	1·90	1·31	1·54	1·02	1·83
	6. Linkinhorne, Cornwall	5 ,,	13 ,,	23 ,,	42·2	13·53	0·72	1·01	0·67	1·91	0·87	1·29	0·70	1·46
	7. Newton Abbot, Devon	8 ,,	16 ,,	26 ,,	?	11·81	0·79	2·63	1·79	1·72	1·71	1·76	1·29	2·18
	8. Sherborne, Dorset	11 May	24 May	1 ,,	21·7	10·61	0·24	1·18	0·17	1·51	0·71	0·84	0·20	1·35
	9. Stourton, Dorset	11 ,,	29 ,,	6 ,,	27·6	11·60	0·87	1·28	1·46	1·22	1·08	1·34	1·17	1·25
1940.	10. Kingsdon, Somerset		11 June	18 June	63·5	11·26	0·66†	0·98‡						
	11. Jealott's Hill, Berks.		27 May	5 ,,	12·3	8·94	1·51†	3·07‡						
	12. Swell, Somerset		11 June	18 ,,	42·0	10·60	0·77†	1·77‡						

All results are expressed as percentages of oven-dried material.

• The nitrogenous dressings caused significant increases in yield.

† 23 lb. nitrogen applied per acre.

‡ 46 lb. nitrogen applied per acre.

TABLE 2. *Nitrogen Fractions as Percentages of Total Nitrogen-content*

		Fertilizer	True protein				Ammonia				Amide				Nitrate			
				Very late	Late			Very late	Late			Very late	Late			Very late	Late	
			No N	17	17	34	No N	17	17	34	No N	17	17	34	No N	17	17	34
1938.	1. Jealott's Hill, Berks.	S/A		85	85	87		0·9	1·2	1·2		4·1	3·5	5·1	4·8		0·3	0·1	0·3	Nil
	,, ,,	N/S	88	86	89	85	1·0	1·0	0·9	0·7	4·4	4·3	4·0	4·4	4·3	0·3	0·3	1·0	N.D.	0·4
	,, ,,	N/C		87	86	87		0·9	1·2	1·1	0·9	5·4	4·9	5·5	4·7		0·9	0·5	0·2	N.D.
1939.	2. Bideford, Devon	N/C	81	82	79	82	82	2·6	2·7	2·7	2·5	1·9	5·0	5·3	4·8	4·7	6·1	0·5	0·6	0·9	0·5	1·2
	3. Curry Rivel, Somerset	N/C	85	80	80	82	80	1·0	1·8	1·2	1·1	1·0	4·3	4·8	5·4	5·0	4·1	0·4	1·3	1·5	N.D.	1·0
	4. Jealott's Hill, Berks.	S/A		85	84	87	85		1·5	3·2	1·4	2·7		5·0	4·2	3·9	4·5		0·4	0·5	0·1	0·3
	,, ,,	N/S	87	85	81	86	84	1·0	0·9	1·3	1·0	1·0	4·3	4·5	4·1	4·8	4·9	0·1	1·7	3·2	0·6	0·4
	,, ,,	N/C		85	81	85	83		1·5	1·5	1·5	1·4		3·7	4·3	4·2	4·3		0·4	1·0	0·5	0·7
	5. ,, ,,	S/A		87	82	88	87		2·6	6·5	1·2	1·5		4·3	3·7	4·2	4·5		0·3	0·1	0·2	0·3
	,, ,,	N/S	88	87	81	89	88	1·0	1·0	1·0	0·9	1·2	4·6	4·7	5·3	5·0	4·8	0·2	1·0	3·2	0·3	0·4
	,, ,,	N/C		90	88	89	87		1·3	1·6	1·0	1·0		4·5	4·8	4·7	4·5		Nil	0·7	0·6	0·6
	6. Linkinhorne, Cornwall	N/C	80	80	82	83	83	1·3	1·5	1·4	1·4	1·3	4·8	4·8	4·6	4·6	4·4	Nil	1·1	1·1	0·4	Nil
	7. Newton Abbot, Devon	N/C	87	86	85	86	87	1·4	1·3	1·2	1·5	1·7	5·7	5·3	5·1	4·7	4·7	0·3	0·4	0·4	0·3	Nil
	8. Sherborne, Dorset	N/C	89	87	86	90	87	1·3	1·2	1·3	1·6	1·2	5·2	4·8	4·3	3·9	3·9	0·5	0·1	0·9	1·3	0·7
	9. Stourton, Dorset	N/C	86	85	84	84	85	1·1	1·5	1·7	1·2	1·4	4·3	4·5	5·3	4·3	4·8	0·4	0·7	0·9	0·7	0·3
1940.	10. Kingsdon, Somerset	S/A	80	80†	80†																	
	11. Jealott's Hill, Berks.	S/A	82	82†	79†‡																	
	12. Swell, Somerset	S/A	83	83†	80‡																	

S/A = sulphate of ammonia; N/S = nitrate of soda; N/C = nitro-chalk.

† 23 lb. nitrogen applied per acre.

‡ 46 lb. nitrogen applied per acre.

N.D. = Not determined.

Effect on aftermath.—To determine aftermath yields it would be necessary to fence off the plots to protect them from stock in the remainder of the field, and this was only found practicable in the 1938 experiment at Jealott's Hill. In this experiment the yield of aftermath was increased by 2 cwt. of dry matter per acre by the 34-lb. dressing of nitrogen. Observation of the plots in several of the other experiments showed that the late and very late nitrogen applications to the hay crop increased the growth and improved the colour of the aftermath.

Discussion

The results confirm that soluble nitrogenous fertilizers applied 7–20 days before mowing increase the protein-content of hay. It may not be amiss to emphasize that these late dressings of nitrogen are given with the intention of increasing the protein-content of the hay and the yield of aftermath. The need for early dressings of nitrogen to increase the yield of hay remains.

The dressing applied about 7 days before mowing was just as effective as a dressing applied about 14–20 days before mowing even in 1940, when the weather during the interval between applying the nitrogen and mowing was extremely dry. If growth conditions are good, dressings applied about 20 days before mowing may increase yields as well as increase protein-content; in such cases the increase in protein-content will be somewhat lower but the nitrogen will have been effectively used by the crop.

The extra nitrogen absorbed by the crop was in almost every case wholly built up into true protein. Heavy dressings of sulphate of ammonia (2 cwt. or more per acre) may tend to increase slightly the ammonia-content of the herbage, but this will have no effect on the feeding-value. Very late applications of 2 cwt. or more of nitrate of soda per acre may tend to cause slight increases in nitrate-content of the herbage, but it seems that the increases are too small to have any harmful effect on the health of stock.

The possible effect of late nitrogen dressings on clovers is important. These late dressings do not increase the growth of grasses and, therefore, do not suppress clovers by shading. To avoid damage by tramping and passage of the drill the late nitrogen dressings are applied when the crop is dry, and experience has also shown that the nitrogen fertilizers do not burn the clovers.

Watson and Horton [4] found, from examination of many samples of hay, that the protein equivalent was highly correlated with the crude-protein content and could be calculated from the latter by means of the following equation:

Protein equivalent = (0·7093 × crude protein)—2·173. Applying this equation to the average of the results quoted in Table 1 gives the following figures for hay (15 per cent. moisture):

Treatment of hay	*Crude protein per cent.*	*Protein equivalent per cent.*
Untreated	8·5	3·8
1 cwt. nitrogen fertilizer per acre .	9·4	4·4
2 ,, ,, ,, .	10·0	4·9

A 10 cwt. cow needs 0·6 lb. protein equivalent per day for maintenance and 0·5 lb. protein equivalent is sufficient for the production of one gallon of milk. A ration of 20 lb. of hay would supply:

Treatment of hay	*lb. protein equivalent in ration*	*Sufficient for maintenance + gallons*
Untreated	0·76	0·32
1 cwt. nitrogenous fertilizer per acre .	0·88	0·56
2 ,, ,, ,, . .	0·98	0·76

Twenty lb. of untreated hay would supply sufficient protein equivalent for maintenance plus one-third of a gallon of milk. Twenty lb. of hay dressed with 1 cwt. fertilizer per acre would supply sufficient *extra* protein equivalent for 0·24 gallons, whilst 20 lb. of hay dressed with 2 cwt. of fertilizer per acre supplies sufficient *extra* protein for 0·44 gallons.

The effect of the late nitrogen dressings on the starch equivalent of the hay can only be conjectured. These late dressings did not affect the yield, so any increase in protein-content must be accompanied by a decrease in carbohydrate material. A decrease of 1 or 1·5 per cent. in starch equivalent is, however, more or less negligible on a material having a starch equivalent of about 30. In actual fact, a sli ht increase instead of a decrease might occur, because an increase in protein-content and protein digestibility may be accompanied by a small increase in starch equivalent owing, for example, to reduced lignification of cellulose. For all practical purposes it can be assumed, however, that late dressings of nitrogen do not affect the starch equivalent.

In the preliminary note calling attention to the effect of late nitrogen dressings on the protein-content of hay, reference was made to the experience of Sprague and Hawkins [5] that a drill with a team of horses caused little or no injury to the hay crop if the herbage was dry. A few farmers in this country have tried late applications of nitrogen on a practical scale and their experience confirms Sprague's. In the small-plot experiments reported in this paper the fertilizers were broadcast by hand and, to get even distribution, the operator trod fairly extensively on the plots, but in all cases the crop was erect again within twenty-four hours.

Summary and Conclusions

The results of twelve experiments conducted in 1938–40 show that soluble nitrogenous fertilizers, if applied to meadow hay 7–20 days before mowing, increase the protein-content of hay without affecting the yield. One cwt. per acre of sulphate of ammonia, nitrate of soda, or nitro-chalk gave an average increase of 1·0 per cent. in crude-protein content; at 2 cwt. fertilizer per acre, the average increase was 1·75 per cent. Lack of rain did not affect the results.

The extra nitrogen absorbed by the crop was converted into true protein, and the proportion of non-protein nitrogen compounds was unaffected with two minor exceptions. The ammonia-content was

increased slightly by the high dressing of sulphate of ammonia, and nitrate was increased slightly by the high dressing of nitrate of soda in two experiments. The slight increase in ammonia-content almost certainly has no effect on the feeding-value, and it seems unlikely that the increased nitrate-content would have been harmful.

Aftermath yields were measured in one experiment only and were increased. In several of the other experiments it was observed that the late and very late applications of nitrogen to the hay crop increased the growth and improved the colour of the aftermath.

About 25–30 per cent. of the nitrogen applied was absorbed by the hay crop and probably about 10 per cent. more by the aftermath. This is quite as much as is recovered in a hay crop dressed in the usual way with nitrogen fertilizer some weeks before mowing.

If fed at 20 lb. per head to milking cows hay dressed late with 1 and 2 cwt. of nitrogenous fertilizer per acre supplied on an average enough protein equivalent for maintenance plus 0·24 and 0·44 gallons respectively.

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SOME FACTORS INFLUENCING THE WEIGHT OF TABLE DUCKLINGS AND THE HATCHABILITY OF DUCKS' EGGS

J. M. RENDEL

(*Department of Biometry, University College, University of London*)

Material and management.—Two breeds of duck were used in this experiment, (1) Aylesbury ducks bred at the National Institute of Poultry Husbandry, and (2) a breed started by Mr. Allport of Felmingham, Norfolk, which originated as a cross between pure Aylesbury and White Campbell. The birds had been selected for weight and egg-laying qualities over a period of five years before they were bought for this experiment. These breeds will be referred to as N.P.I. and Allports.

Twenty-four ducks and six drakes were selected from each breed. All the drakes were young birds; the ducks consisted of birds just coming into their first laying-season (ducklets) and birds just coming into their second laying-season (yearlings). Of the 24 N.P.I. ducks, 12 were ducklets and 12 yearlings; these were housed in 6 pens, each pen containing 1 drake, 2 yearlings, and 2 ducklets. Of the 24 Allport ducks, 15 were yearlings and 9 ducklets; these were also housed in 6 pens, 3 containing 1 drake, 2 yearlings, and 2 ducklets, and 3 containing 1 drake, 3 yearlings, and 1 ducklet. By mating the ducks in this way any influence the drake might have on the offspring of his mate was spread as evenly as possible over the two age-groups. All pens were identically housed. The birds had no swimming-water, but were provided with drinking-water *ad lib.*

All birds were trap-nested from October 15, 1938, until July 31, 1939, when nearly all the birds had stopped laying. Each egg was dated and marked with the number of the duck which laid it. The eggs were washed immediately after collection, and were then left to dry off for an hour, when they were weighed to the nearest gram. Eggs were stored for not more than one week before setting. Every egg with a sound shell was set regardless of size and shape, but abnormal eggs, e.g. those with double yolks, were not set.

Eggs were pedigreed in muslin bags on the 25th day of incubation. Each duckling was wing-banded before being put out into the brooder-house. For every duckling wing-banded, the weight of the egg from which it hatched, the date on which the egg was laid, and the duck that laid it, were recorded.

Each hatch was treated as one unit for rearing, so that all ducklings, regardless of breed and of the age of dam, were reared together under the same conditions. At 10 weeks of age the ducklings were weighed individually.

The first lot of ducklings were hatched on February 27, the next lot a fortnight later, and thereafter once a week until June 6. The first hatch was small owing to poor fertility. The second and third hatches showed a low hatchability and a very high mortality during the first 4 days after hatching. The reason for this mortality was not established,

but may have been due to faults during incubation. These hatches have not been included in the experiment, except for records of fertility. The next 10 hatches were satisfactory and were used for the experiment. The total number of birds reared from these 10 hatches was 542 N.P.I. and 516 Allport ducklings.

Table 1 gives a summary of the year's results. The Allport ducklets gave a rather poor figure for hatchability, otherwise there is little if any

TABLE 1. *Fertility, Hatchability, and Mortality during the First Year*

		N.P.I.		*Allport*	
		Old	*Young*	*Old*	*Young*
Fertility, per cent.		76·3	78·5	68·7	81·3
Hatchability, ,, ...		58·5	69·5	67·8	56·6
Mortality, ,, ...		4·04	7·33	8·48	8·48
Mean wt. of ducklings in gm. at 10 weeks	Male	2,521	2,461	2,072	2,084
	Female	2,384	2,354	1,902	1,925

difference between the two breeds in fertility, hatchability, and mortality. The Allport is a smaller breed than the N.P.I., and Allport ducklings averaged about 450 gm. per bird less than the N.P.I.

Age of parent and weight of duckling at 10 weeks.—The mean weight of ducklings produced by yearlings has been compared with the mean weight of ducklings produced by ducklets. The weights obtained from the 10 hatches are given in Table 2, where the weights of male and female ducklings are treated separately.

TABLE 2. *Mean Weight (in grams) of Ducklings at Ten Weeks*

	N.P.I.				*Allport*			
	Males		*Females*		*Males*		*Females*	
Hatch	*Progeny of old*	*Progeny of young*	*Progeny of old*	*Progeny of young*	*Progeny of old*	*Progeny of young*	*Progeny of old*	*Progeny of young*
1	2,439	2,325	2,319	2,351	2,049	1,962	1,891	1,850
2	2,604	2,416	2,392	2,422	2,129	1,986	2,009	1,822
3	2,430	2,325	2,382	2,228	1,964	1,988	1,890	1,873
4	2,536	2,571	2,327	2,291	2,064	2,098	1,866	1,908
5	2,442	2,430	2,385	2,185	1,916	2,057	1,818	1,865
6	2,444	2,552	2,574	2,451	2,166	2,224	1,963	2,046
7	2,512	2,409	2,384	2,310	1,987	1,993	1,867	1,999
8	2,537	2,442	2,398	2,310	2,122	2,094	2,002	1,948
9	2,671	2,577	2,481	2,453	2,224	2,199	2,001	2,002
10	2,565	2,509	2,496	2,319	2,172	1,982	2,096	1,985

An analysis using 'Student's' t test shows that there is no significant difference in weight between the offspring of Allport yearlings and ducklets: for male ducklings $t = 0{\cdot}679$, for females $t = 0{\cdot}354$, $n = 9$. There is a significant difference, however, between the offspring of N.P.I. yearlings and ducklets: for males $t = 2{\cdot}324$, for females $t = 3{\cdot}154$, $n = 9$. So that in the N.P.I. stock the old breeders were superior to the young, whereas in the Allport stock there was no difference between

them. An analysis of variance shows that there is no significant difference between hatches or between sexes. The results of the analysis are given in Table 3. It is impossible to say what this difference means on one year's work as there is no way of comparing the yearlings with the ducklets.

Egg-weight and duckling-weight.—The 'within dams' regression of duckling-weight on egg-weight was calculated for eight groups; Allports and N.P.I., ducklets and yearlings, males and females again being treated separately, there being 60 to 100 pairs of observations in each group. Effects of seasonal variation were to some extent avoided by eliminating

TABLE 3. *Average Excess in Weight (grams) of the Offspring of Yearlings over Ducklets*

	N.P.I.		*Allport*	
Hatch	*Males*	*Females*	*Males*	*Females*
1	114	−32	87	41
2	188	−30	143	187
3	105	154	−24	17
4	−35	36	−34	−42
5	12	200	−141	−47
6	−108	123	−58	−83
7	103	74	−6	−132
8	95	88	28	54
9	94	28	25	−1
10	56	177	190	111
Mean	62·4	81·8	21·0	10·5
t	2·324	3·154	0·679	0·354

differences between early, medium, and late hatchings in calculating sums of squares and products; the three hatching-periods were each of about three weeks. The analysis includes the offspring of 33 dams; the remaining 15 dams did not give at least one observation for each period (Table 4). Five of the eight groups show a significant positive regression. Of the three remaining groups, two show a positive regression (one of which borders on significance) and one a very small negative regression. It follows that, in general, the weights of the offspring of a single dam are positively associated with the weights of the eggs from which they were hatched. Table 4 indicates that a variation of 1 gm.

TABLE 4. *Regression of Duckling-weight on Egg-weight*

	Males	*Females*
N.P.I., young . . .	+18·9*	+12·1*
N.P.I., old . . .	+13·2*	+11·7*
Allport, young . .	+8·7	+15·6*
Allport, old . . .	−2·2	+4·8

* Significant.

in egg-weight above or below the mean is accompanied by a corresponding variation of about 12 gm. in duckling-weight. As the variation in the egg-weight of each duck covers a range of about 20 gm., this repre-

sents a possible variation of 240 gm. in duckling-weight due to egg-weight alone: a very large variation compared with the weight of the duckling, which averages about 2,400 gm. for N.P.I. and 2,000 gm. for Allport.

The seasonal rise in egg-weight and duckling-weight is shown in Table 5. From an analysis of variance it is found that the rise in egg-

TABLE 5. *Seasonal Variation in Egg-weight and Duckling-weight*

		Egg-weight (grams)			*Duckling-weight (grams)*		
	Hatching-period	*1*	*2*	*3*	*1*	*2*	*3*
N.P.I.	Young males	74·03	73·95	75·55	2,373	2,461	2,505
	Young females	72·49	73·67	74·80	2,371	2,297	2,367
	Old males	70·53	73·67	76·85	2,486	2,494	2,577
	Old females	73·83	71·50	75·82	2,364	2,383	2,460
Allport	Young males	69·21	73·39	76·10	1,992	2,100	2,303
	Young females	69·62	72·13	76·18	1,832	1,932	1,978
	Old males	69·98	71·70	74·36	1,955	1,992	2,055
	Old females	70·00	70·64	74·23	1,869	1,813	1,898

weight is significant in six of the eight groups, and the rise in duckling weight in two. After correcting duckling-weight for egg-weight in these two groups, the rise in duckling-weight is no longer significant. After correcting duckling-weight for egg-weight in the remaining six groups, it is seen that in four of them the ratio between the mean square for seasonal variation and the mean square for the error-term is very much reduced, though the rise in duckling-weight is not significant. In one of the two remaining groups there is a negative regression (Table 4) and in the other a slight seasonal fall in duckling-weight. There seems, in fact, to be a tendency for duckling-weight to rise towards the end of the season, and this rise is associated with a corresponding rise in egg-weight that is much more marked.

Position of egg in the clutch as it affects body-weight.—When once it begins to lay, the duck is generally a very persistent layer. It may lay an egg a day for as many as 200 consecutive days; as a rule, however, the heavier breeds lay in clutches of from 3 to 12 eggs, with a pause of a day or so between each clutch. To find out whether the duckling hatched out of the first egg in a clutch had any advantage over a duckling from an egg laid later in the series, clutches of from 4 to 10 eggs were examined in the following manner. The mean weight of the ducklings hatched from each dam was first calculated and the weight of the ducklings hatching from the first, second, third, &c., egg in a clutch were then expressed in terms of the mean (Table 6), i.e. a duckling weighing 30 gm. more than the mean duckling-weight of its dam was recorded as +30. The mean weight of eggs from the first to the seventh position calculated in the same manner is given in the same table. We see that there is a steady fall of egg-weight and duckling-weight from the first to the last egg. These results support those obtained in the preceding

section, in that a fall in egg-weight is accompanied by a fall in duckling-weight, and show quite clearly that duckling-weight is influenced by the position in the clutch of the egg from which it is hatched. It seems probable that the effect of egg-position on duckling-weight is associated with its effect on egg-weight.

Effect of position on hatchability.—If the fertile eggs are grouped according to their position in the clutch, and the percentage of eggs hatching in each group then calculated (Table 6), there is no obvious

TABLE 6. *Weight of Egg by Position*

Position of egg in clutch	1	2	3	4	5	6	7
Relative weight of egg (gm.)	3·42	2·54	−0·09	−1·99	−2·41	−2·43	−3·12
Number of eggs	105	105	105	105	70	52	28

Weight of Duckling by Position

Position of egg in clutch	1	2	3	4	5	6	7
Relative weight; duckling (gm.)	34·0	10·2	20·1	−23·8	−1·4	−115·7	−90·2
Number of ducklings	49	66	52	50	39	25	11

Hatchability by Position

Position of egg in clutch	1	2	3	4	5	6	7
Hatchability of fertile eggs, per cent.	67·5	76·1	66·7	64·2	72·6	72·1	48·2
Number of fertile eggs	86	92	87	95	62	43	27

change in hatchability from the first to the sixth position, the hatchability of the seventh position is low, but is based on only 27 eggs, and cannot be regarded as very reliable. As there is no tendency in the first six positions for hatchability to vary in any one direction, it is concluded that the position of the egg in the clutch does not affect its chance of hatching.

Egg-weight and hatchability.—The weight of eggs used in this experiment ranged from 55 to 105 gm. The eggs have been arranged in six groups according to weight at equal intervals, and the percentage of fertile eggs that hatched was calculated for each group (Table 7). All birds having a hatchability of less than 50 per cent. have been excluded. The Table shows that heavy and light eggs do not hatch as well as eggs of medium weight.

Prof. J. B. S. Haldane points out that it should follow that eggs which do not hatch are more variable than eggs which do, and that selection is here acting so as to reduce variation in egg-size. Considering all the fertile eggs that were set we find that for the 1,202 hatched eggs the

mean weight is 73·294 ± 0·188, and for the 688 eggs which did not hatch the mean weight is 73·917 ± 0·292. The difference between the two means is 0·624 and is not quite significant. The variance of the weights of the hatched eggs is 42·27 and of the unhatched 58·34; the ratio of these is 1·38, which, tested with 687 degrees of freedom against 1,201, is highly significant, showing that, as was to be expected, the hatched eggs are much more uniform in weight than the unhatched. The variance of the unhatched eggs would be slightly increased by the inclusion of

TABLE 7. *Egg-weight and Hatchability*

Wt. (gm.)	*No. Eggs*	*Hatch (%)*
85–89	49	65·3
80–84	187	63·6
75–84	367	70·8
70–74	454	70·5
65–69	338	67·8
60–64	93	64·4
Outside range	22	..
Total	1,510	..

those abnormal eggs which were not incubated, i.e. the double-yolked eggs weighing up to 130 gm. and the very small eggs of 14–45 gm.

Discussion

In hens, no connexion has been found between age of parents and the weight of the offspring [1]. In the experiment the old N.P.I. ducks were found to produce heavier offspring than the young, but this was not supported by the results obtained from the other breed, and it seems probable that the difference was due to the old birds being superior for some reason apart from their age.

The weight of the 10-week old duckling has been shown to depend quite considerably on the weight of the egg from which it hatches, and this connexion is found to hold, not only for the slight seasonal rise in egg-weight, but also for the much more marked fall in egg-weight from the beginning of a clutch to the end. It is surprising that there does not appear to be any such connexion in the chick or turkey poult, where no correlation is found between egg-weight and chick-weight after the first week or two [2, 3, 4, 5].

However, Galpin, working on the chick, finds that there is a seasonal variation in egg-weight in the hen which is exactly paralleled by a seasonal variation in the weight of the 6-week-old chick. Both changes appear to be connected with thyroid activity, for as the egg-weight and chick-weight fall, the number of eggs laid increases and the weight of the thyroid decreases; the correlation between egg-weight and chick-weight decreases at the same time.[1]

There appear to be two possibilities: either the thyroid activity of the

[1] As a hen in lay has a much lighter thyroid than the non-laying hen, thyroid-weight is taken to be inversely proportional to thyroid activity.

hen produces a direct effect on the metabolism of the chick, as well as on the egg-weight and egg-number, as suggested by Dr. Galpin, or the reduction in chick-weight can be attributed directly to the lack of egg-material in the lighter eggs. Although chicks and ducks may not be strictly comparable, the fact that the fall in egg-weight at the end of a clutch was found to be accompanied by a fall in duckling-weight, argues in favour of the possibility that egg-weight plays at least some part in the seasonal variation in chick-weight; for the fall in egg-weight at the end of a clutch when the duck is about to take a rest can hardly be attributed to the increased activity of the thyroid, as can the seasonal fall in the hen's weight, accompanied as it is by an increase in egg-number.

As was found to be true for hens [6], heavy and light eggs do not hatch as well as medium-weight eggs. This is another example of selection acting against variability, the eggs which fail to survive being more variable in weight than the eggs which do, so that ducks with a narrow range in egg-weight might produce more surviving offspring than ducks with a very variable range.

From the practical point of view we have two conflicting factors to deal with. By selecting heavy eggs, heavier ducklings will be obtained, but at the cost of a lowered hatchability. If medium-weight eggs are selected, the hatchability will be increased, but the weight of the ducklings will not be quite so high. In either case the total weight of duckling produced from a given number of eggs will be about the same; whether heavy or medium-weight eggs are the more economical to incubate will depend, to a large extent, on the cost of rearing fewer heavy birds as against a rather larger number of lighter birds. In any case it is obviously desirable to reject any eggs much below the mean weight.

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THE RELATIONSHIP OF PLANT NUMBER AND YIELD IN SUGAR-BEET AND MANGOLDS

D. J. FINNEY

(*Rothamsted Experimental Station, Harpenden, England*)

1. *Introduction*

DURING the last two years an extensive survey of wireworm infestation and the consequent damage to crops has been undertaken by the Ministry of Agriculture Plant Pathological Laboratory and provincial Advisory Entomologists, in consultation with Rothamsted Experimental Station. In the present season estimates of wireworm population have been made by a sampling process for about 400 fields, and wherever possible these have been followed by further sampling for plant density at an early stage of growth and later for yield. The results of this investigation are not yet complete, but it is clear that one important aspect of the problem is the extent to which plant elimination, by wireworm attack early in the growing-period, can be taken as an indication of the ultimate effect on yield.

Available evidence on the effect on yield of a reduction in plant density should throw some light on this point. Within the limits of normal agricultural practice, any elimination of plants will allow neighbouring plants greater freedom of growth. The increased size of these remaining plants will, to some extent, compensate for their reduced number and the loss in yield will thus be proportionately less than the loss in stand. With the object of discovering the extent of this compensation, experimental data from a number of sources have been examined, and the results of this examination are described below.

2. *Factory Sugar-beet Series*

For each of 52 experiments in the Factory Sugar-beet Series of the years 1933–9 [1] the error regression of yield on plant number has been obtained, these experiments being mostly those for which plant number showed great variability from plot to plot. The mean plant number (1,000 per acre) was 25·75 and the mean yield of sugar (cwt. per acre) was 33·75. Thus the mean weight of sugar from 1,000 plants was 1·311 cwt.

The regression coefficient of the 52 yields on the corresponding plant numbers was $0{\cdot}647 \pm 0{\cdot}356$; thus, from experiment to experiment, a decrease of 1,000 plants was accompanied by a decrease of 0·65 cwt. of sugar or 49·4 per cent. of the mean yield of 1,000 plants.

A similar percentage may be calculated for each experiment separately, from the regression coefficient within the experiment. This quantity is a measure of the independence of growth of (absence of competition between) the roots. Clearly a value of zero means that changes in plant density had no effect on yield, and thus there was complete compensation for any decrease in density by an increase in

weight per plant. On the other hand, a value of 100 per cent. means that competition was so completely absent that a decrease in plant number had no associated compensation of increased weight per plant. The mean value of the percentage (k) for the 52 experiments was 53·4, which agrees very closely with the corresponding figure above calculated between experiments. There was no evidence of any association between the values of k and the mean plant densities of the experiments, but there was, as might reasonably be expected, an increase in k with decreased yields. If s represents the yield of sugar in cwt. per acre, the regression equation of k on s is

$$(k-53{\cdot}4) = -1{\cdot}62(s-25{\cdot}8),$$

the standard error of the regression coefficient being $\pm 0{\cdot}77$.

This evidence suggests that for a normal yielding crop, and within reasonable limits of plant density, any loss of plants will result in a loss in yield of about 50 per cent. of that which would occur if the remaining plants gave no compensatory increase in yield per plant. The heavier the yield, the greater will be the degree of compensation and consequently the less will be this proportionate loss, the estimated percentage decreasing by 1·6 for every 1 cwt. increase in total sugar per acre.

Of the 52 values of k, 12 are actually greater than 100 per cent., implying an increase in yield for each additional plant greater than the mean weight of a plant. It is likely that some over-estimation of the regression coefficient of yield on plant number occurs in some experiments, because of a correlation between plant number and plot fertility, such that plots with a high plant number yield more *per plant* than those with a lower plant number receiving the same treatment. This would result in an over-estimation of the values of k. It is thus possible that the true reduction in yield for a decrease in stand is less than the estimated value of 50 per cent.

3. *The Influence of Gaps*

In 1926 an experiment to test the effect on yield of a plant population reduced below a full stand by gaps was performed by E. Lindhard and M. Jørgensen of the Royal (Danish) Agricultural College [2]. Two varieties of mangold (Sludstrup Barres, a large-topped variety, and Taarøje Barres, a small-topped variety) were tested at Lyngby and sugar-beet (Kleinwanzleben N) was grown at the College farm. At each centre the seed was sown at a drill width of 60 cm., the plants being later thinned to exactly 25 cm., to give a plant density of 66,700 per hectare (27,000 per acre). The experimental area had 19 rows at least 50 m. in length.

Between 8 and 14 days after thinning, artificial gappiness was introduced by removing from every fourth row runs of 1, 2, 3, or 4 successive plants, 6 plants being left standing between gaps. In any given row all gaps were of the same length. These rows are referred to as 'gap rows'; of the three rows between successive gap rows, the outer two are 'neighbour rows' and the middle one a 'normal row'. The remaining plants of a gap row may be classified as 'gap roots' (immediately adjacent to

the gaps) and 'normal roots'. The runs of 1, 2, 3, or 4 plants in a neighbour row parallel and adjacent to a gap are called 'neighbour roots'; other plants of the same row, including those diagonally adjacent to a gap, are again called 'normal roots'. There were 20 replicates of each type of gap.

For each gap row, separate determinations of yield and dry matter per root were made for gap roots and normal roots. Separate figures were also obtained from the corresponding neighbour rows for neighbour roots and normal roots. The results are shown in Table 1 (Table 7 of [2]).

TABLE 1. *Weight of Normal, Gap, and Neighbour Roots for Gaps of Different Size*

		Weight in gm. per root									
		Total					*Dry matter*				
Row	*Root*	*1 gap*	*2 gaps*	*3 gaps*	*4 gaps*	*Normal mean*	*1 gap*	*2 gaps*	*3 gaps*	*4 gaps*	*Normal mean*
		Sugar-beet (Landbohøjskole)									
Gap	Normal	662	680	650	642	658	156	159	153	151	155
	Gap	935	1,040	1,113	1,070	..	213	234	249	240	..
Neighbour	Normal	651	660	657	640	652	153	155	154	151	153
	Neighbour	667	696	737	732	..	157	163	172	170	..
		Mangolds—Sludstrup (Lyngby)									
Gap	Normal	1,083	1,092	1,062	1,085	1,080	131	132	129	132	131
	Gap	1,406	1,623	1,613	1,790	..	165	186	185	203	..
Neighbour	Normal	1,159	1,172	1,149	1,193	1,158	139	140	138	143	140
	Neighbour	1,272	1,234	1,252	1,333	..	151	147	149	157	..
		Mangolds—Taarøje (Lyngby)									
Gap	Normal	1,244	1,278	1,331	1,344	1,299	132	135	140	141	137
	Gap	1,681	1,856	1,877	2,165	..	171	186	188	213	..
Neighbour	Normal	1,342	1,330	1,372	1,351	1,349	140	139	143	141	141
	Neighbour	1,227	1,381	1,455	1,464	..	130	144	151	152	..

From this table it is possible to estimate the actual loss in yield caused by a gap of given size after allowing for the compensatory increased growth of adjacent plants. Thus, from the sugar-beet data in the 4-gap column, the expected yield from the two gap roots and eight neighbour roots is

$$2 \times 1070 + 8 \times 732 = 7996 \text{ gm.}$$

Had there been no gaps, the expected yield from roots in the corresponding positions would be

$$6 \times 642 + 8 \times 640 = 8972 \text{ gm.}$$

The total loss for the gap is 976 gm., or 1·52 times the weight of a normal root in the same rows (641 gm.). These estimated losses are shown in Table 2 (which is part of Table 9 of [2]).

Table 1 shows there to have been little difference between the weights of normal roots in gap and in neighbour rows. The increased weight of

the two gap roots is very marked for all three varieties of root; the difference from normal increases with the length of gap, the rate of increase for mangolds showing little sign of falling off even for a 4-gap, though for sugar-beet there appears to be no effect on these roots of increasing the gap beyond 3 root-places. Neighbour roots, on account of their greater distance, cannot so readily take advantage of the gap and their increases in weight are comparatively small, though again the effect increases steadily with increasing gap size.

From an examination of 800 plots, Pedersen [3] has concluded that the distribution of gaps of different sizes is substantially that which would be expected if the elimination of plants took place entirely at random. In a further paper [4] the same author applied this result to the

TABLE 2. *Loss in Yield for Gaps of Given Size, in Units of the Weight of One Normal Root*

	Total				*Dry matter*			
	1 gap	*2 gaps*	*3 gaps*	*4 gaps*	*1 gap*	*2 gaps*	*3 gaps*	*4 gaps*
Sugar-beet . . .	0·13	0·72	0·85	1·52	0·22	0·86	1·08	1·78
Mangold (Sludstrup) .	0·21	0·82	1·42	1·76	0·32	0·99	1·67	2·11
Mangold (Taarøje) .	0·47	0·95	1·82	2·11	0·55	1·10	1·99	2·39
Mean . . .	0·27	0·83	1·37	1·80	0·36	0·99	1·58	2·09

estimation of the loss in yield resulting from a given percentage reduction in stand. For any such percentage the proportions of gaps of different length caused by plant elimination was estimated according to the law of randomness and the appropriate loss in yield for gaps of each length was then obtained from Lindhard and Jørgensen's experimental data. Unfortunately these data gave no information on gaps of more than 4 root-places, and it was therefore necessary to obtain the required figures by extrapolation of a smooth curve. Such a method is clearly open to objections, but its effects on Pedersen's conclusions can scarcely be very great below 50 per cent. plant elimination, since below that figure few large gaps will occur. A further point which should be noted is that no allowance is made for non-independence of gaps. With a large percentage loss in stand the gaps will seldom be separated by six plants, as in Lindhard and Jørgensen's experiment, and not infrequently gap roots will occur which have gaps on either side. Gaps may also occur side by side in adjacent rows. Such situations will presumably lead to underestimation of the loss in yield.

Pedersen's tables may conveniently be expressed in terms of the coefficient k, previously defined as the loss in yield for a reduced plant density as a percentage of the normal yield of the number of plants eliminated. Indeed, Table 8 of [4] gives the values of this coefficient for yields of dry matter, the two varieties of mangold having been averaged; Table 3 below is extended so as to cover total root-weight also.

The percentage k is the complement of e, the coefficient of utilization defined by Pedersen (i.e. $k = 100 - e$). For both crops it is noticeable

that the values are about 8 per cent. higher for dry matter than for total weight, showing that the compensatory increases in weight of plants which benefit from empty root-places are made at the expense of a decreased proportional dry-matter content. The figures for dry matter

TABLE 3. *Values of k, the Loss in Yield as a Percentage of Normal Yield of Missing Plants*

Percentage of empty root-places	*Sugar-beet*		*Mangolds*	
	Total	*Dry matter*	*Total*	*Dry matter*
5	17	26	35	45
10	18	27	37	46
20	23	31	40	49
30	27	35	43	52
40	33	40	47	55
50	39	46	52	59
60	47	53	57	64
70	56	61	64	70
80	68	71	73	77

in Table 3 are fairly satisfactorily in agreement with the average value of 50 per cent. found for the sugar-beet series examined earlier, though the coefficient there showed no association with plant density.

4. *Experiments in Denmark*

Pedersen concluded his second paper with an examination of the results of 2,300 experiments on mangolds, conducted by the Danish Agricultural Organizations in Sjælland, Fyn, and Jylland in the period 1926–30. In Table II of the paper he shows these experiments grouped according to their plant density, the mean yield for each group being given. The results for Sjælland and Fyn are very similar and for the present purpose have been combined; in Jylland both yields and plant densities were lower. The experiments are summarized in Table 4.

TABLE 4. *Results of Danish Mangold Experiments, 1926–30*

	Sjælland and Fyn	*Jylland*
No. of experiments	1,416	886
Mean yield (hkg./ha.)	748	603
Mean plant density (1,000/ha.)	63·2	51·7
Mean yield per 1,000 plants (hkg.) . . .	11·8	11·7
Decrease in yield per 1,000 plants reduction (hkg.)	6·56	6·05
k (per cent. proportional decrease) . . .	55·6	51·7

Fig. 1 shows, for each set of experiments, the straight line and parabola which best represent the yields in terms of plant number. Measuring plant density (x), in 1,000 per hectare and yield (y) in hectokilograms per hectare, the line and parabola for Sjælland and Fyn are

$$y = 344{\cdot}6 + 6{\cdot}39x,$$

and

$$y = 133{\cdot}1 + 13{\cdot}13x - 0{\cdot}0520x^2.$$

The corresponding curves for Jylland are

$$y = 319{\cdot}3 + 5{\cdot}48x,$$

and

$$y = -43{\cdot}5 + 19{\cdot}54x - 0{\cdot}1305x^2.$$

It is apparent that, for the first group of experiments, the straight line is almost as good a representation of the results as is the parabola, but

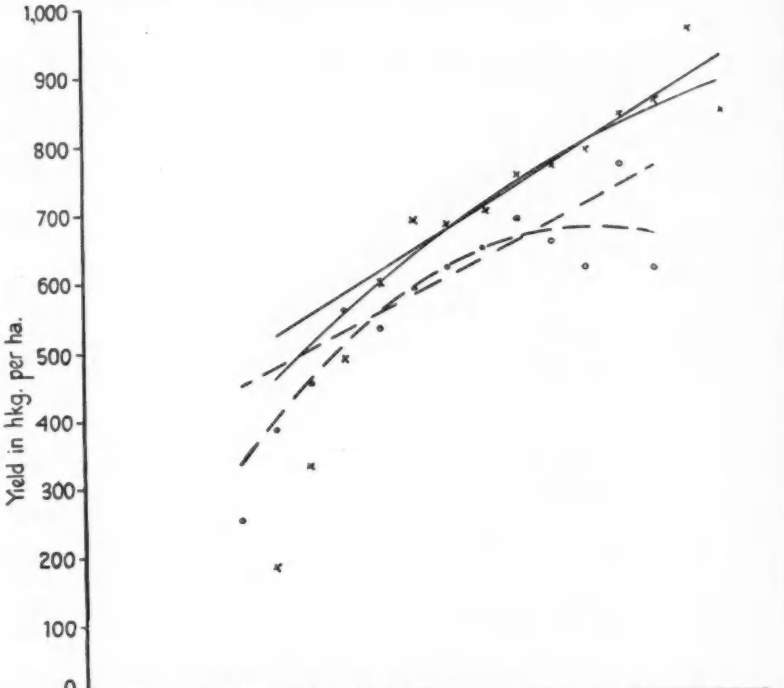

Fig. 1. Plant density and yield in mangold experiments of the Danish Agricultural Organizations, 1926–30.

(The experiments were grouped according to plant density. The yields plotted are the means for densities of 21,000–25,000, 26000–30,000, . . . plants per ha.)

× and ———— Sjælland and Fyn (1,416 experiments)
○ and —— —— Jylland (886 experiments).

for the Jylland experiments the parabola is successful in showing the much reduced response of yield to increasing plant density when the latter exceeds 50,000 per ha. Indeed, there are indications here that the yield may actually be reduced when the density exceeds 80,000 per ha. In passing it may be observed that, though these parabolas have

not been constrained to show zero yield for $x = 0$, their continuations do in fact pass reasonably close to the origin.

By differentiation of the equations of the parabolas, the decrease in yield for a loss of 1,000 plants per ha. corresponding to any given plant density may be found. Taking the mean density for each series of experiments, it may be shown that with a plant population of 63,200 per ha. in Sjælland and Fyn, a decrease of 1,000 plants per ha. might be expected to produce a decrease in yield of 6·56 hkg. per ha.; the corresponding decrease for a population of 51,700 per ha. in Jylland is 6·05 hkg. per ha. Expressing these decreases as percentages of the mean yield per 1,000 plants, the values of the coefficient k are found to be 55·6 and 51·7 per cent., figures which show remarkably close agreement with each other and with those obtained in the first section of this paper.

5. *Experiments in Holland*

In 1930 and 1931 experiments on the weight of individual beet were conducted at the Sugar-beet Institute, Bergen-op-Zoom, Holland [5, 6]. On three plots in the first year, and on one plot in the second, each root was weighed separately and its distance from the two adjacent roots in the same row was measured. The mean distance was multiplied by the width between rows to give the area occupied by the individual root and

TABLE 5. *Results of Dutch Sugar-beet Experiments, 1930–1*

	1930			
	Plot A	*Plot B*	*Plot C*	*1931*
No. of beet	465	939	895	3,204
Mean yield (hkg./ha.)	489	555	530	356
Mean plant density (1,000/ha.)	55·7	59·1	61·5	54·8
Mean yield per 1,000 plants (hkg.)	8·8	9·4	8·6	6·5
Decrease in yield per 1,000 plants reduction (hkg.)	4·11	4·22	3·93	3·99
k (per cent. proportional decrease)	46·8	44·8	45·6	61·6

the mean root-weight in successive ranges of areas was calculated. These figures were then converted to show the number of beet per ha. and the corresponding mean yield in kg. per ha.

These results can scarcely be considered comparable with those discussed earlier. The growth of adjacent roots will be far from independent and competition-effects complex. By contrast, the other small-scale experiments were so designed as to permit the examination in some detail of the competition between adjacent roots at various distances. In the large-scale experiments, on the other hand, only average competition-effects for a plot or for a field were under discussion. Nevertheless there is some interest in treating the yield and plant-density figures in the same way as the Danish large-scale experiments. Table 5 summarizes the results.

As with the Danish data, the straight lines and parabolas best representing the yield–plant-density relationship were calculated. In all cases there is an appreciable curvature, and in 1931, the higher yielding year, there is a suggestion of a maximal yield at about 80,000 plants per

ha. In the same manner as previously, the expected decreases in yield for a reduction of 1,000 plants per ha. below the mean density were calculated and expressed as percentages of the mean yields of those plants. The values of k thus obtained were lower in 1930 and higher in 1931 than for the experiments previously discussed. Even so, none of the figures departs far from 50 per cent., and thus all show fair agreement with the British and Danish series.

6. *Summary*

Examination of the relationship between plant density and yield in four widely different series of experiments on sugar-beet and mangolds indicates that, with a normal plant population, any elimination of roots may be expected to be accompanied by about half the proportionate loss in yield. The values obtained for the proportion of the normal yield of the eliminated roots which is lost, a coefficient representing the degree of absence of competition, range only from 44·8 to 61·4 per cent. This range becomes even narrower (49·4 to 55·6 per cent.) if the Dutch experiments, which are not strictly comparable with the others, are omitted. With stands of greater than average density, the Danish and Dutch experiments agree in showing increasing competition, and thus a reduction in the expected loss from plant elimination; in the British series of experiments no such tendency was evident. It is possible that in the British and Danish large-scale experiments (and to a lesser extent, in the Dutch data), association between reduction in stand and the inherent fertility of the experimental sites may have led to over-estimation of the loss in yield; in the Danish small-scale experiments this can scarcely have occurred since stand was there artificially controlled.

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THE AGRICULTURAL ECONOMY OF THE HILL PAGANS OF DIKWA EMIRATE, CAMEROONS (BRITISH MANDATE)[1]

STANHOPE WHITE

(*Assistant District Officer, Northern Nigeria*)

With Plate 7

Introduction.—The Hill Pagans of the Dikwa Division of the British Cameroons occupy the westernmost of the peninsulas of hills which run out from the massif of Adamawa in the south, into the plain surrounding Lake Chad. This peninsula, now known as the Mandara Mountains, was first seen by European eyes in 1823, by Major Denham on his journey with Barca Gana from Kukawa via Mongonu and Dikwa to Mora. In 1851 it was seen from the village of Palamari in what is now the District of Auno in Bornu Province by Barth, who called it by its Kanuri name of Mount Deladeba or Dalantuba. This peninsula, in its northern part, is like a roof-ridge, with precipitous sides and little or no flat ground on the summit; but south of the Gwoza Pass the ridge is wider and is cut by longitudinal and transverse valleys into a system of more or less isolated hills with connecting ridges that form the watersheds. The hills run up to about 3,000 ft. above the plain, or about 3,500–4,000 ft. above sea-level.

The ridge is formed of very coarsely crystalline granite, with pegmatitic veins which become in parts pure quartz: in the south of the area, basaltic dykes are found which disintegrate into slate-like particles. The granite weathers in the usual tropical fashion into smooth, rounded blocks with a black patination, some of the blocks being of huge size.

The inhabitants of this hill area belong to eight different clans, some of which may have a common ancestry, whilst others are distinct; all, however, have similar customs and are at the same level of cultural development. These clans are as follows: Wakara (roughly 12,900 strong), Hidkala (7,200), Azgavana (9,400), Kuvoko (1,700), Matakum (1,600), Buhe (9,200), Chikkide (4,600), and Glebda (5,700). Each clan's area is divided into villages, and in some of the latter are to be found small groups of members of earlier peoples who were dispossessed of their land when the present groups entered the area. The most widespread of these earlier peoples are called the Aganjare, who are to be found scattered over the whole area. They are now practically assimilated with the other tribes or clans, but retain one distinguishing feature in that they alone possess a 'Juju' for rain. The peoples now dominant all affirm that they came from the south at some distant period, but it is impossible to make any rough estimate of the time when this immigration occurred, nor are the reasons known which caused it.

Until the British occupation in 1919 the people were confined almost exclusively to the hills, and the neighbouring plains were cultivated only to a small extent by the farmers from villages on the slopes

[1] The opinions given in this article are those of the writer: the Nigerian Government accepts no responsibility for them, or for the accuracy of the facts as stated.—*Ed.*

above, except on the eastern side of the spur, where the Glebda clan had occupied the plains for about 2 miles from the foot of the hills, and had retained a footing on only a few isolated foothills. The spur formed a nodal point, where met the rival powers of the Fulani of Madagali, the Kanuri of Bornu, and the Mandara of Mora, and the inhabitants of this area were liable to be raided for slaves by any or all of these powers. As the latter were all essentially mounted men, living in the plains was too dangerous, in fact impossible, so all houses had of necessity to be located on the sides of the spur, whence, if the occasion arose, a rapid retreat could be made to inaccessible fastnesses among the rocks; the sole exception was the Glebda clan, but they surrounded their houses and farms with huge hedges of 'wait-a-bit' thorn, which effectually stopped anything in the way of mounted raids. Apart from this area, anyone venturing on to the plains was liable to capture by small raiding parties on the look-out for such prey, whilst corn crops were liable to destruction or pillage at any time. For these reasons, it is unlikely that, except in the Glebda area, cultivation, or the collection of bush products, such as honey, firewood, or thatching grass, or the grazing of animals, was possible at more than a few hundred yards from the foot of the hills. The present inhabitants are vague as to the former limits which prevailed, limits which probably varied as the strength of the slave-raiding powers waxed or waned, though it is likely that parties of youths at all times ranged far and wide in search of game or the cattle of the dwellers on the plains. Up to 1919, however, it is safe to say houses were found exclusively on the hills, as were the vast majority of the farms and grazing areas, with the exception of those of the above-mentioned Glebda clan. Since that date the Hidkala, Buhe, Chikkide, and Wakara clans have spread to a considerable extent over the plains, but the remaining three have remained in their old hill-top positions.

The total area now occupied by these Pagans in British territory is approximately 300 square miles. No accurate census has so far been possible in this area, but in 1939 the strength of each clan was roughly as given above, assuming there are 5·5 persons per compound. The number of compounds in that year was 9,534, and taking this estimate, which is the best yet assumed, the total population is about 52,000, which gives a density of approximately 170 to the square mile. The area occupied in the pre-British occupation era was about 200 square miles, and even if we assume the population has doubled in the last forty years—a doubtful assumption—this still gives a density of 130 per square mile for a period when the hills probably supported their greatest population. For comparison, Lord Hailey's *Survey* (pp. 2 and 806–11) gives the densities of population in Uganda, Northern Nigeria, British India, Java, the Transkei, the Kikuyu Reserve, and the Kavirondo Reserve, as 39, 40·1, 200, 817·5, 58·1, 283, and 145, respectively; so it will be seen that this area supports what, by African standards, is a very high density of population.

This density is only possible because of the very high order of the Pagan agricultural practice, which, moreover, contains practically every

principle that Agricultural Departments throughout Africa are trying to instil into the 'backward peoples'. These principles are:

1. Conservation of soil and prevention of erosion.
2. Animal husbandry—wherever poverty does not forbid it—giving mixed farming.
3. Improvement of soil conditions by the use of farmyard and every other available source of manure.
4. A system of crop rotation.
5. Planting and the protection of trees.

It is no exaggeration to say that these people destroy nothing that is of any possible value for their farms or their stock, and utilize everything that can be utilized.

Soil conservation and prevention of soil erosion.—Parts of these hills consist of areas of huge boulders thrown together in indescribable confusion; they are practically uncrossable to all but a Pagan, and have no place in the economy of the latter except for the collection of bamboos that are found in the northern parts of the area. Elsewhere, the hills are covered from foot to summit with an endless system of dry-stone wall-terraces. It is impossible to make more than a rough guess at the total mileage of these terrace-walls, but in this small area it is of the order of 20,000 miles. These terrace-walls have been carefully built up after the fashion of the dry-stone walls of northern England, and the work is in no way inferior to that of the latter. The height of individual terraces varies from a few inches, composed of one line of stones, up to huge walls, 10 ft. or so in height. The present inhabitants all say that their forefathers found the present system of terraces on entering the area, and it is obvious that it must have taken centuries of work to bring the system to its present state of perfection. It is therefore impossible to give any date to the work, but one late Palaeolithic and one early Neolithic artifact have been found by the writer on terraces in the north-eastern part of the spur; no other remains have so far been found. It is a remarkable sight to see the miles of terraces in the south of the area, following every valley and spur for miles and extending vertically for some 2,500 ft. Tops of hills have been surrounded by the topmost wall of the terraces, and the space then infilled to give flat expanses of varying size. Where the slope is gentle, the terraces are very wide, but the vast majority are of the order of 4 ft. high, 5–10 ft. wide; some terraces, however, are simply a few inches wide, and allow one line of corn only to be sown thereon.

Small water-courses on the hills are confined to narrow channels between terraces, whilst on the plains lines of dashi (H.[1]), *Balsamodendron africanum*, and kerana (H.), *Euphorbia barteri* or *E. candelabrum*, are planted across lines of erosion and effectually prevent anything in the nature of gully or 'donga' formation. Larger water-courses on the plains are unfortunately not controllable by these methods, and with the removal of most of the natural cover by the Pagans who have settled on the plains during the last twenty years, gully-formation has occurred on

[1] The abbreviation H. signifies the Hausa name.

an increasingly large scale. This erosion takes place only in the neighbourhood of existing streams, as the Pagan has brought his terrace technique with him from the hills, and has cut large areas of the plains into chequer-board patterns with hedges of *E. barteri* and fascines of thorns or corn-stalks between the stems of the trees, which prevent any new water-courses being formed. In some areas, gentle step-terraces have been formed from the use of fascines held down by large stones, or even by the formation of small mounds of earth thrown up in lines by hoes; whilst in the above-mentioned Glebda area the huge thorn hedges prevent anything in the way of erosion.

On the hills great care is taken of the stone walls. Before the rains start each farmer makes a careful survey of any damage done by grazing animals in the period since the last harvest. The odd stones that have been displaced are carefully replaced, and any holes in the earth of the terrace are infilled—often by the expedient of smashing pebbles of rotten granite to give a coarse gravel; areas of extensive damage are repaired by calling out the youths of the village to the work and then regaling them on the completion of their labours with beer brewed by the owner of the repaired terraces. During the rains no one may leave a path to walk along a terrace, except the owner thereof, lest a carelessly placed foot displace a stone and lead to a wash-out during the next downpour.

It is unfortunate that our occupation of this area has led, in many cases, to the abandonment of the terraces by the hill-side dwellers who have come down on to the plains, whilst the fact that feeding and thatching grass can now be obtained by all on the plains has led to a reduction of the area needed by the hill-top peoples, who formerly had to keep a large area of their terraces under grass only.

In the villages of the Kuvoko clan fighting with the Fulani some forty years ago led to the abandonment of their hill-side terraces and a concentration on their higher ones, whilst one of the best watered valleys in the area has been practically deserted since the early 1930s, when the first locust invasion occurred. This valley is shared by the Azgavana and Matakum clans, the former being entirely in British territory, the latter chiefly in French. The Matakum were reduced to a starving condition by the depredations of the locusts; many hundreds left the hills and are now to be found scattered over southern Bornu attached in small groups to villages of Kanuri. This clan has therefore withdrawn from its outlying terraces, whilst the fact that grass can now be obtained on the plains has led the Azgavana to do likewise.

The abandonment of a terrace means its inevitable destruction, progressing slowly at first and then increasingly fast as more and more places of attack are exposed. The slow and laborious work of centuries in gathering and fixing the earth is washed away in a few rainy seasons, and bare and barren hill-sides are the result. The terraced areas contain many springs and are well wooded; the de-terraced areas are useless slopes of bed-rock with an immediate run-off of rain-water, leading to increased erosion on the plains. The heavy rains of 1937 and the excessively heavy ones of 1938 have done much damage in the area.

Animal husbandry.—In three of the clans, namely the Wakara, Glebda, and Hidkala, the bride price is five head of cattle; among the Buhe, Azgavana, Kuvoko, and Chikkide it is two head of cattle and five goats, whilst among the Matakum it is only five goats. Blood money, paid for the death of a man killed in fighting, is fixed among all at five head of cattle (one cow, two heifers, and two bullocks). This has meant that the greater number of the Pagans have, of necessity, to keep cattle for use in payments of the above types, but there is nowhere that collection of cattle for collection's sake which occurs among the Fulani, and, to a lesser extent, the Masai.

Bullocks are frequently sacrificed to the ancestors of the owner, and the meat then eaten at a communal beer-party. Among the Kuvoko, Hidkala, Buhe, and Matakum, the following custom is also found. Every three years each householder who can afford to do so puts a bullock into a specially prepared hut that contains two small apertures, through one of which the animal is fed, and through the other its manure is removed. It stays thus for three years, never leaving the hut; at the expiration of this period it is sacrificed to the ancestral spirits, beer and meat feasts being the order of the day. The same year a new bullock is similarly enclosed for the next triennial feast. The latest of these killings was in March 1939.

Goats and sheep are kept by all, and they, together with the cattle, are confined to huts at night and during the whole of the rainy season. All are then hand-fed and watered, and bedded down with grass, often brought from great distances. Their manure is carefully collected and utilized (see below). After the harvest, all save the 'three-year plan' sacrificial animals are allowed to roam about the terraces, returning to the huts only at night, and it is amazing to see cows performing mountaineering feats of no mean order, whilst goats and sheep seem to possess the feet of flies.

Among the Azgavana selective breeding is also found. Because the grazing on the terraces is limited, the animals are hand-fed to a certain extent the whole year round. It is therefore no hardship to retain all the cows in the huts on certain days, while the bulls roam the terraces, and vice versa, thus preventing mixing of the sexes and the promiscuous serving of any and every cow by each bull. Certain bulls are not allowed to serve a cow, whilst others become, to all intents and purposes, stud animals. The owner of a cow served by such an animal pays a small fee as soon as it is obvious that the cow is in calf.

Poultry are also kept and during the sowing-period they too are confined to the huts of the farmer. Old pots are filled with chopped grass and earth and inverted near white-ant heaps; the white ants are attracted by the grass, and after a time the pots are taken to the poultry who then enjoy a meal of white ants.

At the end of the rains hay is cut and plaited into long trusses like French loaves, only about 6 ft. long, and the trusses then hung over the branches of trees, generally Gaus (H.), *Acacia albida*, to be away from the depredations of white ants, till required.

Manuring.—As stated above, all animals are bedded down, and the

manure carefully collected and stored in heaps outside each compound. The household's ashes are also collected inside a hut set aside for that purpose. Latrines are built for humans, and the human excreta are also utilized. Before sowing-time, the accumulated human and animal manure is taken out and piled in small heaps on the terraces, whilst corn-stalks and old thatches from the huts of the farmer are burnt in heaps. After the crop has been sown and has appeared above ground, these heaps are carefully scattered round the plants. In the villages, which now occur on the plains, the cattle going to grazing each day generally follow a well-beaten track, and they are often all watered at a central place. At sowing-time these tracks and watering-places are visited daily by the women, and the droppings collected in large baskets for transport to the farms. Household ashes are poured round the plants, but most are used for Aya (H.), the tiger nut (see below). While the crops are growing, the weeds are collected into heaps and left to form compost, which in the following year the farmer takes great care to incorporate in the soil.

Crop-rotation.—On the hill farms the same crop is sown by all clans in any one year. On the plains, where there is plenty of land available, different crops are grown on different plots, but the rotation for each plot from year to year is the same as that practised on the hills. This rotation is:

Janjari (H.), a variety of *Sorghum vulgare*—guinea corn. Sown in 1938 and 1941.
Farin wake (H.), a variety of *Vigna sinensis*—beans. Sown in 1936 and 1939 with a little Maiwa (H.).
Maiwa (H.), *Pennisetum spicatum*—a variety of bulrush millet. Sown in 1937 and 1940 with some beans.

It will thus be seen that only one year in three sees a large corn crop in the hills; the following year beans are the staple crop but a little millet is also sown, so that some corn is available; the third year, the millet is the staple crop, but beans are also sown. In the bean years, too, a little Tamba (H.), *Eleusine corocana*, which gives a millet-like grain, is sown round the edges of the terraces. With this rotation and the use of manure, it is said that plots will yield for as long as ten years; outlying plots which are too far from the owner's house to receive any manure may be used for two years only, and then left fallow for the same length of time.

With all plots, if the fertility of the ground is exhausted, a fallow period of two years is allowed, and then Aya (H.), *Cyperus esculentus*, the tiger nut, is cultivated. The earth is dug out of the terrace, grass piled into the holes, wood-ash and household sweepings poured in on top of the grass, and the earth replaced; crops of the tiger nut are then taken from the plot for two or three years, when it is claimed the full fertility of the soil has been regained.

Maize is grown immediately round each house, but this is not a staple crop, whilst Kwaruru (H.), *Voandzeia subterranea*, the Bambarra ground-nut, and excellent sweet potatoes are also grown on any small

patches that can be spared. Onions are grown on stream-side plots which can be irrigated, by the clans who live on the hill-tops, namely the Kuvoko, Azgavana, and Wakara. Ground-nuts on the plains are a new development; they are chiefly grown as a cash crop, and have no place in the essential economy of these people.

Planting and the protection of trees.—The terraced villages of these peoples are notable for the number of fine trees growing there. Despite the necessity to make use of every patch of ground, no matter how small, for the growth of food crops, trees have a definite place in the Pagans' agricultural system. The following are the commonest, with the uses to which each is put:

Aduwa (H.), *Balanites aegyptiaca*—desert date—leaves and berries for human consumption.

Gau (H.), *Acacia albida*—seeds and leaves are used as fodder for sheep and goats.

Giginya (H.), *Borassus flabellifer*—Deleb palm—seeds eaten; young germinating shoots used as a vegetable; there is now a sale of the male trees.

Madachi (H.), *Khaya senegalensis*—African mahogany—seeds for oil, planks for doors and beds, leaves for animal fodder.

Marike (H.), *Anogeissus leiocarpus*—timber for house building, leaves for animal fodder.

Magariya (H.), *Zizyphus jujuba*—Jujube tree—the seeds are eaten, the leaves are fodder for goats, the sticks used for a variety of purposes.

The Deleb palms are sown by hand, but the others are allowed to propagate themselves. Young trees which have appeared on a terrace are generally uprooted by the farmer, who, however, takes very good care to see that he has enough at various stages of development to supply future needs. Pruning of leaves for animal consumption is carefully carried out by using sickles on poles about 8 ft. long, great care being taken not to damage the tree in any way. Dead wood is carefully cut out for firewood.

This appreciation of the uses of trees is shown by the fact that in the bush on the plains west of Gwoza there are no Madachi (H.) trees except in two villages. These villages are inhabited by offshoots of the Hidkala clan who settled here at least 150 years ago, and whose ancestors brought the seeds for these trees with them.

Conclusion.—In conclusion one may quote Lord Hailey's *Survey* to illustrate how the present methods used by these Pagans are to be regarded not simply as a most interesting example of how an African race has reacted to an unhelpful environment, but as an example of methods of agriculture which it is desirable to perpetuate from a long-term point of view. These people are troublesome administratively, and it is therefore desirable to persuade them to leave their rather inaccessible hills for the open and readily accessible plains. From a scientific point of view it is surely more desirable to take the long-term point of view and to discourage the Pagan from leaving his terracing with its concomitant preservation of water-supplies—preservation which

undoubtedly affects a large area of the plains. Get these people on to the plains and the terracing will go; bare hill-sides will form; erosion will be accentuated on the plains, and probably the water-table will drop—a state of affairs similar to that which has occurred in parts of the Wakamba hills in Kenya Colony. If the younger generation wishes to settle on the plains and lead the easier life which prevails there, then surely an afforestation programme should be considered as of the greatest urgency to ensure that the soil now in position on the hills is not washed away with the destruction of the terraces.

Lord Hailey says, 'It is clear that the most urgent problem in all territories is the introduction of methods which will maintain soil fertility without extensive recourse to shifting cultivation' (p. 960). 'It is only in the last few years that soil erosion has become recognized as one of the major problems facing the governments and peoples of most African territories, and as a problem which is growing yearly more acute' (p. 1056). 'The most ancient, universal, and effective method of increasing absorption and reducing run-off on cultivated land is the use of terraces' (pp. 1064 et seq.). 'The protection of water-supplies, vital to Africa's future, is now recognized to be bound up with the restoration of forest and grass-cover to hill-sides and crests' (pp. 1112 et seq.).

In this small part of Africa, as opposed to the greater part of the continent, an indigenous native agricultural economy has been evolved, which, to a layman at any rate, seems to possess all the desiderata enumerated by Lord Hailey, and to contain nothing which brings permanent harm to the soil, and as such seems to be worthy of every encouragement.

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Zeledufa Village. Wakara tribe, showing houses and stone terraces in the background, and fascine terraces and heaps of burnt straw in the foreground.

A terraced hill-top area. Kuvoko clan.

THE FEEDING-VALUE OF ENSILED JERUSALEM ARTICHOKE TUBERS

A. BONDI, H. MEYER, AND R. VOLKANI

(*Agricultural Research Station, Rehovot, Palestine*)

THE Jerusalem artichoke, *Helianthus tuberosus*, can be cultivated with success in different parts of Palestine; the chemical composition of the tubers has been determined and found to correspond closely with that found for tubers grown abroad. The satisfactory nutrient-content, and in particular the high carbohydrate value of the tubers, suggest that the material might be an economical feed for milk cows. Difficulties, however, attend the storage of the tubers under Palestinian conditions: when lifted from the soil they wilt rapidly, and when allowed to remain in the soil they are liable to rot [1]. Silage experiments with the tubers therefore seemed to be desirable.

The leafage of Jerusalem artichoke has repeatedly been found to yield a good silage [2]. Although in practice the tubers have been ensiled [3], no systematic investigation of the process has, to our knowledge, been undertaken hitherto.

Expt. I. Ensilage of 150 kg. of Jerusalem Artichoke Tubers

The first experiment was carried out in a barrel on October 30, 1936, using a fresh lot of tubers kindly provided by the Agronomy Division of this Station. When the barrel was opened on January 21, 1937, i.e. after three months, the tubers appeared to be well preserved, though somewhat soft. The odour was sourish but not acrid. Mould had not formed. Cows, calves, and sheep consumed the ensiled tubers readily. The results of a partial analysis of the original and final materials are presented in Tables 1 and 2.

TABLE 1. *Determination of Acids in Artichoke Silage* (*per cent.*)

	Water	*Acetic acid*		*Butyric acid total*	*Lactic acid free*
		Free	*Bound*		
Material as received .	78·55	0·36	0·41	0·03	2·23

TABLE 2. *Protein and Sugar in Fresh and Ensiled Artichoke Tubers* (*per cent. of dry matter*)

Material	*Date*	*Crude protein*	*Monoses*	*Bioses and polyoses decomposable by* HCl (1·05)	*Total sugar*	*Water*
Original .	30.x.36	12·50	6·94	56·68	63·62	75·53
Silage . .	21.i.37	12·26	12·21	9·32	21·53	78·55

XUM

Expt. II. Ensilage of a 2-ton Lot of Jerusalem Artichoke Tubers

The second experiment, undertaken on November 5, 1937, comprised 2 tons of fresh tubers, which were charged into a cement tower, 3 m. high and 2 m. in diameter and extending to a depth of ½ m. below the ground-surface. The tubers were finely sliced by machine and closely packed into the tower, which was charged to about one-third of its capacity. The top of the tuber pack was covered by paper, and overlaid with hay and a 40-cm. layer of earth to render the material airtight.

The silo was first opened after 3½ months (February 20, 1938). The silage looked good but was somewhat soft. The odour was acid but not bad. Mould had not developed. During a period of one month samples of the silage material were removed at frequent intervals for determining chemical composition and digestibility. The samples to be analysed were obtained from different 30-cm. layers. Between samplings the silage was kept carefully sealed. The results of the analysis of the original and final materials are given in Tables 3–5.

TABLE 3. *Determination of the Acids present in Artichoke Silage (per cent.). Expt. II (1937–8). Average of Four Samples taken Feb. 20–Mar. 9, 1938*

Acetic acid Matter as received		*Butyric acid Matter as received*		*Lactic acid Matter as received*		
Free	*Bound*	*Free*	*Bound*	*Free*	*Bound**	*Water*
0·12	0·05	0·04	0·015	0·19	0·79	83·18

* Determined on three samples by O. Flieg's method (*Bied. Zentr., B. Tierernähr.*, 1937, **9**, 178).

TABLE 4. *Percentage Composition of Fresh and Ensiled Artichoke Tubers. Ensiled Material: Average of Food Samples taken Feb. 20–Mar. 9, 1938*

	*Crude protein**	*Fat**	*Ash**	*Crude fibre**	*N-free extract**	*Water*
Fresh . . .	7·85	0·48	5·96	6·44	79·27	80·39
Ensiled (average) .	10·15	0·38	11·14	7·99	70·33	83·18

* Calculated on dry matter.

The artichoke silage obtained in the experiments was of good appearance and contained considerable quantities of the desired lactic acid, particularly in the lower layers, but only very slight amounts of butyric acid. The maximum concentration of this undesirable acid in bound and free form was 0·12 per cent., which is not injurious. The pH of the silage fluctuated between 3·8 and 4·6, being especially low in the upper layers; that of the original material was 6·3.

The changes in the chemical composition of the material during ensilage are of interest. The content of crude protein remained almost constant (Tables 2 and 4). N-free extractives showed an average decline of 9 per cent., a loss which must have increased the percentage figures

found for other constituents. The concentration of total sugars (monoses +polysacchrides hydrolysed by acid) dropped markedly in the deeper layers (Tables 2 and 5). About one-quarter of the loss in sugar is accounted for as lactic and acetic acid; the nutrient value of the former approximates to that of sugar [4]. Since no appreciable quantities of alcohol were

TABLE 5. *Carbohydrate-contents of Fresh and Ensiled Artichoke Tubers (Calculated on dried material). Four Ensiled Samples taken Feb. 20–Mar. 9, 1938*

		Monoses			*Bioses and polyoses decomposable by acids*				
	Date	*Aldoses calc. as glucose*	*Ketoses calc. as fructose**	*Total monoses*	*Aldoses formed by acid treatment calc. as glucose*	*Fructose formed by acid treatment*	*Inulin calc. from fructose†*	*Total*	*Total sugar calc. as monose*
Fresh .	5.xi.37	0	7·14	7·14	52·11	22·85	20·55	74·96	82·10
Ensiled (average of 4 samples)	20.ii.37 to 9.iii.37	0·77‡	10·24‡	11·72	15·87‡	21·50‡	19·32‡	43·25	55·0

* Determined by Kruisher's method; see A. Beythien, *Laboratoriumsbuch für den Nahrungsmittelchemiker*, 1932, p. 275.
† Determined according to H. Pringsheim and D. Krueger; see G. Klein's *Handbuch der Pflanzenanalyse*, II. i. 867 (1932 edit.). ‡ One sample only.

formed it may be concluded that most of the remaining sugar deficit was converted into sugar acids. The inulin-content (as calculated from the increase in fructose on acid hydrolysis) remained at 20 per cent. throughout the storage.

Expt. III. Digestibility of Ensiled Jerusalem Artichoke Tubers

The digestibility of the tuber ensilage was determined on three sheep by a procedure that is being published elsewhere [5]. As the sheep could not be maintained exclusively on the tuber diet, they were given a daily ration of 500 gm. hay in addition to the 2 kg. of tuber silage. The digestibility of the hay was determined in a separate experiment, using the same sheep. Almost all the silage given was consumed by the animals, but where, as in the first sub-period of the experiment, small quantities were rejected, this loss was allowed for in the calculations.

The coefficients found with different animals and in different sub-periods for the protein and N-free extractives contained in the silage showed good agreement; and the results indicate that ensilage does not involve important changes in digestibility.

	Crude protein	*N-free extract*
Digestibility coefficients of silage . .	68·1	96·9
,, ,, ,, fresh tubers [6] .	67·0	93·0

The results found for the digestibility of crude fibre in the tuber silage are not immediately comprehensible. The calculated value of over 100 per cent., which is patently impossible, might be due to an

increase in the digestibility of the crude fibre of the hay in the ration of hay + tubers, following the addition of the tuber constituent. A special bacterium brought in with the tubers might be involved. An experiment to test this point is intended.

In general it may be stated that ensilage made from Jerusalem artichoke tubers is a good sugar-rich feed, comparable in nutritive value to sugar-beet or orange-peel.

Summary. Jerusalem artichoke tubers give a palatable silage of good digestibility and satisfactory nutrient-content. The material is rich in desirable lactic acid and contains but very little butyric acid.

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FERTILIZER POLICY IN WAR-TIME: THE FERTILIZER REQUIREMENTS OF ARABLE CROPS

E. M. CROWTHER AND F. YATES

(Rothamsted Experimental Station, Harpenden, England)

Summary.—In order to formulate a flexible fertilizer policy which will ensure maximum agricultural production and make the best use of available fertilizer supplies, all published results of one-year fertilizer experiments conducted since 1900 in Great Britain on the main arable crops, and also of similar series of experiments in other northern European countries, have been summarized.

The problem of determining the best dressings for the different crops under varying conditions is discussed, and rules are given for the allocation of a given amount of fertilizers to the different crops which are applicable both for a single farm and for the whole country.

The main conclusions are as follows:

1. The responses to phosphate and potash are substantially reduced when dung is applied, but crops are equally responsive to inorganic nitrogen on dunged and undunged land. Consequently smaller dressings of phosphate and potash are required on dunged land, but no reduction should be made in the nitrogenous dressing.

2. The current level of nitrogenous manuring, both in absolute amount and relative to that of the other fertilizers, is too low, particularly where dung is also given. Considerable increases in agricultural production would result from the greater use of nitrogen, especially on cereals.

3. Additional phosphate is needed for root crops, especially in the wetter districts and on phosphate-deficient soils, including much of the newly ploughed grass-land.

4. The general policy of making fertilizers in short supply available only for the most responsive crops (already adopted in the case of potash) is the correct one. It appears, however, that potatoes should receive some potash, even in the presence of dung, unless supplies are very short.

5. The responses to phosphate and potash (in contrast to nitrogen) vary markedly with soils and districts. Consequently, in order to ensure the most efficient utilization of soil reserves and fertilizer supplies, local knowledge or soil analysis should be used as far as possible. When, as is at present the case with potash, there is a fertilizer shortage, this is particularly important.

Introduction

The changing needs and conditions of war demand a flexible fertilizer policy, which must be directed towards the maximum production of the most necessary crops, and at the same time ensure every possible economy in the use of fertilizers themselves.

Both potash and phosphate have to be imported. Potash will in any event be in short supply, and additional supplies of phosphate can be justified only if they effect more than a corresponding economy in the imports of food.

Farmers, therefore, have to support their claims for increased supplies of fertilizers by evidence of increases in production. Such evidence must be quantitative, and not merely qualitative. Equally they are vitally concerned in using fertilizers to the best advantage, not only in the national interests but also in their own interests—for fertilizers cost money and the amounts available are limited.

To use fertilizers to best advantage demands accurate knowledge of their effects, and this can only be obtained from experiments. It is now well known that the responses to fertilizers are very variable, depending on crop, soil, season, &c. Consequently final conclusions must never be based on the results of a single experiment, or even a series of experiments on a single farm, but on a large number of experiments on different farms, conducted in different years, and on different crops.

Once the results of a large number of experiments are available the average responses to the various fertilizers can be determined. Such averages, in so far as they refer only to broad districts and cover many soil types in the district, must, of course, be interpreted in the light of local knowledge and experience, but they provide a sound working basis for assessing the general needs of the various crops. With a sufficiently accurate and extensive series of experiments, averages for particular districts and soil types can also be obtained. Moreover, if soil analyses have been conducted on the experimental land, the relationship between the actual responses and the values given by soil analysis can be studied. In this country, however, there is not yet a sufficient body of data for this to be possible. Indeed only on sugar-beet and potatoes has any progress been made in testing the association between responses and the results of soil analysis.

In order to obtain an accurate picture of the average effects of the various fertilizer components, and so enable a sound fertilizer policy to be drawn up, all fertilizer experiments conducted in Great Britain since 1900,[1] and similar experiments in certain other northern European countries, have recently been brought together and summarized. The present paper describes the results of this inquiry, and shows how they affect the fertilizer policy of the farmer.

It is perhaps somewhat remarkable that such a summary has never previously been made. Probably the main cause of this is the heterogeneity of the experiments and the inaccessibility of the results. It is much to be deplored that no comprehensive series of experiments on varying levels and combinations of the three standard fertilizers has yet been undertaken in this country for any crop except sugar-beet. Even on the Continent little has been done in this direction, but there are far greater numbers of simpler experiments. The British experiments have, however, given consistent results and these results find strong confirmation from the parallel continental experiments.

The results in the present inquiry are restricted to those of single-year

[1] This date was chosen since changes in methods of farming and consequent variations in soil fertility are likely to make the results of earlier experiments progressively less applicable. In particular, during the last few decades of the nineteenth century there was a large increase in the use of artificial fertilizers.

experiments, and, in consequence, underestimate the total effect of fertilizers by omitting the residual or cumulative effects. But under war-time conditions the immediate response by the crop to which the fertilizer is supplied is of first importance, and evidence is growing to suggest that there is a general tendency among farmers to exaggerate the value of residual effects of fertilizers used in good crop rotations, since highly responsive crops which are heavily manured are normally followed by less responsive crops. Thus phosphates may make all the difference between the success and failure of a root crop and yet have negligible effects on the following cereal crop.

Although in some respects the results of the inquiry merely confirm current beliefs and practice, they also reveal some unexpected facts and strongly support the contentions that have already been made in certain quarters that the main war-time fertilizer policy of this country should be to encourage the use of more nitrogenous fertilizers. This will result in more profit to the farmer and more food for the nation even should the supplies of phosphate and potash be relatively curtailed.

In summarizing the experiments the responses given with different levels of dressing have been reduced to responses to a standard dressing by means of the response curves discussed later. The standard dressings actually chosen were:

Sulphate of ammonia, 1·2 cwt. per acre (0·25 cwt. N.).

Superphosphate, 3 cwt. per acre (0·5 cwt. P_2O_5).

Sulphate or muriate of potash, 1 cwt. per acre (0·5 cwt. K_2O).

These values were chosen as being about equal to the average dressings used in the experiments themselves. They are of course low for the root crops.

In the Danish and East Prussian experiments this adjustment could not be made, since in the original reports it was assumed that the responses were proportional to the amounts of fertilizer over the range of dressings normal for each crop.

Average responses.—The average responses shown by the various crops are given in Tables 1 and 2. Each value is accompanied by the number of experiments from which it was derived. For roots the experiments in the British Isles were subdivided into those with and without dung. For cereals only those without dung are included. This subdivision was not possible for the continental experiments, but the majority of the root crops were grown with, and cereals without, dung.

In the original analysis Great Britain was divided into eight districts,[1] but for economy of presentation the results from districts showing similar responses have been combined. Thus one set of values is shown for nitrogen, three for phosphate, and three for potash.

The mean values for Great Britain are simple averages of all experiments, but the general mean was obtained by weighting the averages for each country by the number of experiments, with an upper limit of 200,

[1] The districts originally chosen for England were as follows: *South-west*: Cornwall, Devon; *West Midlands*: Somerset, Wiltshire, Gloucester, Worcester, Warwick, Hereford, Shropshire, Stafford, Cheshire, Lancashire; *North*: Yorkshire, Westmorland, Durham, Cumberland, Northumberland; *South and East*: all other counties.

TABLE 1. *Response of Root Crops to Fertilizer Treatment*

	Mean response (tons/acre)				*Number of experiments*			
	Swedes	*Mangolds*	*Sugar-beet*	*Potatoes*	*Swedes*	*Mangolds*	*Sugar-beet*	*Potatoes*
NITROGENOUS FERTILIZER (0·25 cwt. N per acre)								
With dung:								
Great Britain	2·3	2·6	0·92	0·86	186	183	56	284
Ireland	1·4	2·7	..	1·42	268	286	..	60
Denmark	2·2	2·6	1·19	0·62	3,198	3,494	440	1,153
South Sweden	2·6	3·0	1·46	0·84	267	404	1,452	404
East Prussia	..	..	..	0·90	..	..	..	728
General mean	2·1	2·8	1·28	0·85	3,919	4,367	1,948	2,629
Without dung:								
Great Britain	2·2	3·1	0·88	1·07	330	98	227	212
Ireland	2·2	..	..	..	162	..	..	..
PHOSPHATIC FERTILIZER (0·50 cwt. P_2O_5 per acre)								
With dung:								
S. and E. England	2·0	0·5	0·84	0·36	13	82	21	68
W. Mid. and N. England	1·3	1·3	?	0·26	84	99	8	104
SW. England, Wales, and Scotland	3·5	1·4	?	1·18	84	27	1	75
Great Britain	2·3	1·0	0·66	0·55	181	208	30	247
Ireland	4·3	1·8	..	0·84	387	206	..	449
Denmark	1·8	1·1	0·76	0·54	2,774	3,011	434	844
South Sweden	1·6	1·7	0·45	0·49	247	417	1,557	355
East Prussia	..	..	..	0·64	..	..	..	725
General mean	2·5	1·4	0·61	0·61	3,589	3,842	2,021	2,620
Without dung:								
S. and E. England	2·5	0·7	0·42	0·93	78	22	147	80
W. Mid. and N. England	3·7	1·6	0·38	0·66	65	30	34	105
SW. England, Wales, and Scotland	5·9	4·9	?	1·48	133	24	3	18
Great Britain	4·4	2·4	0·41	0·84	276	76	184	203
Ireland	10·8	..	..	4·15	313	..	..	14
POTASSIC FERTILIZER (0·50 cwt. K_2O per acre)								
With dung:								
S. England	1·3	1·2	0·11	0·45	19	104	27	103
W. Mid., N. England, Wales	0·5	2·3	0·28	0·34	100	102	11	136
Scotland	1·8	..	?	1·32	62	..	1	66
Great Britain	0·9	1·7	0·17	0·55	181	206	39	305
Ireland	1·3	3·0	..	0·91	62	236	..	412
Denmark	0·5	1·0	0·28	0·47	3,425	3,518	451	1,189
South Sweden	0·7	1·4	0·30	0·46	253	420	1,557	347
East Prussia	..	..	..	0·21	..	..	..	705
General mean	0·9	1·8	0·29	0·52	4,121	4,380	2.047	2,958
Without dung:								
S. England	0·7	1·8	0·42	1·04	89	52	165	127
W. Mid., N. England, Wales	2·3	2·3	0·50	1·38	89	28	46	123
Scotland	3·1	..	?	1·96	191	..	8	12
Great Britain	2·3	1·9	0·44	1·23	369	80	219	262
Ireland	3·4	..	..	..	148	..	..	..

a procedure which prevents undue weight being given to countries with very large numbers of experiments. The means of groups of less than ten experiments are not shown in the Tables.

TABLE 2. *Response of Cereal Crops to Fertilizer Treatment*

	Responses in cwt. grain per acre			*Number of experiments*		
	Wheat	*Barley*	*Oats*	*Wheat*	*Barley*	*Oats*
NITROGENOUS FERTILIZER (0·25 cwt. N per acre)						
Without dung:						
Great Britain	3·4	3·7	3·4	100	61	86
Ireland	4·4	..	2·7	135	..	180
Denmark	4·2	3·8	3·6	381	3,312	2,275
South Sweden	3·7	4·9	4·2	240	241	122
East Prussia	3·2	3·8	4·2	171	211	313
General mean	3·8	4·1	3·6	1,027	3,825	2,976
PHOSPHATIC FERTILIZER (0·5 cwt. P_2O_5 per acre)						
Without dung:						
S. and E. England	?	0·4	?	5	57	7
W. Mid., N. England	?	0·8	2·2	9	25	22
S.W. England, Wales, Scotland	..	?	1·2	..	9	31
Great Britain	0·3	0·6	1·5	14	91	60
Ireland	..	..	2·8	..	..	150
Denmark	0·6	1·8	1·7	162	3,334	2,108
South Sweden	0·4	0·9	1·4	201	223	141
East Prussia	1·9	1·8	2·3	168	205	304
General mean	1·0	1·4	2·0	545	3,853	2,763
POTASSIC FERTILIZER (0·5 cwt. K_2O per acre)						
Without dung:						
S. England	?	0·4	0·8	3	49	13
W. Mid., N. England, Wales	?	0·4	0·1	9	25	12
Scotland	..	?	1·0	..	8	30
Great Britain	2·3	0·4	0·8	12	82	55
Ireland	..	..	1·3	..	..	150
Denmark	0·5	0·8	0·5	128	3,734	2,559
South Sweden	0·4	0·4	1·0	200	223	142
East Prussia	0·7	0·8	1·0	169	206	308
General mean	0·6	0·6	0·9	509	4,245	3,214

All but a small proportion of the experiments were conducted on ordinary commercial farms, and examination of the differences between different series of experiments suggests that there is little bias through the selection of abnormally rich or poor soils.

For phosphate and potash, but not for nitrogen, there was evidence that the responses to fertilizer fell off as the basic fertility of the soil

increased. As might well be expected poorer soils tended to give greater responses. Phosphate and potash behave differently from nitrogen, partly because they are retained in the soil to build up reserves, and partly because these reserves provide particularly favourable conditions for responses to nitrogen.

In most of the experiments each fertilizer was tested in presence of moderate amounts of the other principal fertilizers. The more accurate and comprehensive modern experiments also give information on the effects of each fertilizer on the responses to the others.

The continental experiments differ from the British in that the majority of experiments on crops other than potatoes were made with nitrate fertilizers, those on sugar-beet and mangolds with Chile nitrate of soda, and the others mainly with synthetic nitrate of lime. Nitrates, especially nitrate of soda, usually give better responses per unit nitrogen than sulphate of ammonia, but the difference is to a large extent offset by the extra cost of unit nitrate nitrogen. The continental experiments on potassic fertilizers were made almost exclusively with 40 per cent. potash salt.

A close study of the responses given in Tables 1 and 2 shows that whereas, as might be expected, there are certain irregularities, the values on the whole are very consistent. The agreement between the means for various crops in Great Britain and the general means are remarkably close. To some extent, however, this must be regarded as fortuitous, particularly for the case of phosphate, where there are large variations between different parts of Great Britain.

Influence of dung.—Leaving aside for the moment the differences between crops, the most remarkable feature of the results is the small difference between the responses to nitrogen in the absence of dung and in the presence of dung. One reason which might account for this is that the experiments with dung were conducted on more exhausted land (which was dunged just because it was more exhausted) with the consequence that they responded better to nitrogen because their needs were greater. In order to obtain more definite information on this point, which is of considerable theoretical and practical importance, certain series of experiments which tested the response to nitrogen both in the presence and the absence of dung were abstracted separately. These comparisons confirmed the general conclusion that dung has little effect on the response to nitrogenous fertilizers.

The responses to phosphate and potash on the other hand are substantially reduced in the presence of dung, and from the values given in Table 1 the general reduction for each of these fertilizers may be roughly assessed at 50 per cent. Even these reductions are somewhat smaller than might be expected from the average nutrient contents of dung as shown by chemical analysis. A similar examination of experiments which tested the responses to phosphate and potash both in the presence and absence of dung, gives somewhat greater reductions, particularly in the case of potash.

The explanation of these facts would appear to be as follows:

Dung is a source of the three nutrients considered, as well as of others less generally important. In addition, it improves the physical condition

of the soil. The aggregate effect of the improvement by dung, and the fact that it is normally used on the more exhausted soils, render the crops particularly responsive to the nutrients supplied by added fertilizers. Since most soils are deficient in available nitrogen the response to nitrogenous fertilizers is high even in the presence of the available nitrogen supplied by the dung. The exhaustion of phosphate and potash, which are retained in the soil, is normally less drastic, and the effects of added phosphatic and potassic fertilizers are reduced through the amounts of these nutrients supplied by the dung; the reduction is, however, less than would be expected from the actual amounts in the dung, owing largely to the previous partial exhaustion of the soil.

Practical recommendations for the manuring of dunged and undunged land can reasonably be based on the values of the average responses given in Table 1. This will make automatic allowance for the fact that dung tends to be used on somewhat poorer land.

The average responses to dung in the British experiments were extracted in the same manner as for fertilizers and reduced to a standard dressing of 10 tons per acre. The results are shown in Table 3 for crops grown without fertilizers and with fertilizers respectively.

TABLE 3. *Crop Responses to 10 Tons of Dung per acre*

	Responses in tons per acre			*Number of experiments*		
	Swedes	*Mangolds*	*Potatoes*	*Swedes*	*Mangolds*	*Potatoes*
Fertilizers absent:						
S. and E. England .	4·6	4·2	2·0	43	13	41
W. Mid. and N. England . . .	6·1	5·5	3·8	72	18	121
SW. England, Wales, and Scotland . .	7·1	9·4	3·4	78	51	72
Great Britain . .	6·4	7·7	2·8	193	82	234
Fertilizers present:						
Great Britain . .	2·6	2·7	1·4	84	21	132

The average responses are large, especially in the wetter regions and where no artificials are used. Potatoes, mangolds, and swedes show similar percentage responses. It is clear that if supplies of dung are limited, potatoes should have preference, since the financial returns from the increases in yield of potatoes are relatively much greater than from the root crops, particularly when artificial fertilizers are also used.

Regional variation in response.—The responses to nitrogen show very little variation, and a single set of mean responses has therefore been shown. Potash does show some variation, the responses in general being greater in the north than in the south. The differences are, however, not sufficiently large or well established to be taken into account, and in the subsequent discussion of optimal dressings single mean values for Great Britain have been taken for the whole of the country.

The situation with regard to phosphate is entirely different. Here there are marked variations in response; the wetter regions show higher

responses than the drier south and east of England. These differences have therefore been taken into account in the subsequent discussion.

These differences in phosphate-response are of course well known. The effect of increasing rainfall on the response to the phosphate may act directly through its effect on crop-growth and the length of the growing-season, and it may act indirectly through the soil. Most soils in wet districts are acid because lime is readily lost by drainage, and acid soils stand in particular need of phosphatic fertilizers. This is illustrated in Table 4, which shows how the response of sugar-beet to the standard dressing of superphosphate varied with the reaction of the soil in some experiments in South Sweden.

TABLE 4. *Response of Sugar-beet to Superphosphate in South Sweden*

Soil reaction	*pH*	*Tons sugar-beet roots per 3 cwt. superphosphate*	*Number of experiments*
Acid . . .	below 6·5	1·03	180
Slightly acid . .	6·7 to 7·0	0·68	169
Slightly alkaline .	over 7·0	0·33	169

In wet regions and on acid soils phosphatic manuring is obviously of the utmost importance. At the present time the need will be especially great on the newly broken-up grass-land of the wetter regions. The need for lime as well naturally remains, for liming acid soils not only increases crop yields but also allows phosphates to remain available much longer. The greater effect of dung in the wetter regions is also to be ascribed largely to the phosphate and potash it supplies.

Relative responses of different crops.—Tables 1 and 2 may now be condensed. In this condensation it has been assumed that the ratio of the responses of the different crops is similar in all districts. This appears to be broadly true, except possibly for swedes, which are not a particularly suitable crop for the south and east of England and appear to show rather smaller responses in this district.

Contrary to the general belief, there appear to be no great differences between the responses of the different cereal crops, and they have consequently been grouped together. Wheat gave a lower average response than oats to phosphate, and in the continental experiments rye proved the most responsive of the cereals to phosphate. These differences are almost certainly accounted for by the tendency to grow wheat on soils and in regions which have low phosphate-requirements, whereas rye is normally grown on poor acid sands.

The summary of the various responses to the standard dressings is shown in Table 5, where the mean yields and values of the various crops, and their starch and protein equivalents are also shown. The prices of swedes and mangolds have been raised somewhat above conventional estimates in view of the scarcity of imported feeding-stuffs. An allowance was also made for the effects of fertilizers on sugar-beet tops, which were valued at 14*s.* per ton. The price of cereal grain was increased to 15*s.* per cwt. to make some allowance for the additional straw.

TABLE 5. *Average Responses to Standard Dressings of Fertilizers for Root Crops grown with, and Cereals grown without, Dung*

Standard dressings per acre

0·25 cwt. N = 1·2 cwt. sulphate of ammonia.
0·50 ,, P_2O_5 = 3·0 ,, superphosphate.
0·50 ,, K_2O = 1·0 ,, muriate or sulphate of potash.

Note. For roots grown without dung the responses given should be increased by 10 per cent. for nitrogenous manures and by 100 per cent. for potassic and phosphatic manures.

Response in tons roots or cwt. grain	*Swedes*	*Mangolds*	*Sugar-beet*	*Potatoes*	*Cereals*
Sulphate of ammonia	2·1	2·7	0·9	0·9	3·5
Superphosphate					
S. and E. England	1·2	0·7	0·3	0·3	0·7
W. Mid. and N. England	1·8	1·0	0·4	0·5	1·0
SW. England, Wales, Scotland	3·0	1·7	0·7	0·8	1·7
Sulphate or muriate of potash	1·0	1·6	0·25	0·55	0·7
Mean yields with fertilizer	20	25	11	9	21
Value per ton roots or cwt. grain	23*s.*	19*s.*	60*s.*	110*s.*	13*s.* 6*d.*
Starch equivalent, per cent.	7·3	6·5	15·0	17·8	67·5
Protein equivalent, per cent.	0·7	0·4	0·6	0·8	8·1

Nitrogen.—Potatoes, mangolds, and swedes show average responses of the order of 12 per cent. Sugar-beet is less responsive in roots (about 9 per cent.) but owing to its cash value, its high energy-content, and the additional response of about 1·3 tons of tops for the standard dressing, the total return in starch equivalent is the highest of all crops, and the cash return at present prices is second only to that from potatoes.

Grain crops show average responses of the order of 20 per cent. to 1·2 cwt. of sulphate of ammonia or its equivalent. Contrary to a common opinion, the large number of experiments here and abroad show little or no clear differences between the four cereals, wheat, barley, oats, and rye, in their responses to nitrogenous fertilizers.

Phosphate.—Swedes showed much greater percentage responses to phosphate than any other crop, the responses in the absence of dung ranging from about 20 per cent. in south and east England to 50 per cent. in the north of Scotland. Potatoes and mangolds showed about half the percentage responses of swedes. Sugar-beet showed still smaller responses.

The cereals, too, showed only small percentage responses to phosphate. There is thus abundant justification for the normal practice of restricting phosphatic manures to the root and ley breaks of the rotation, but this conclusion may need modification for two sets of conditions not covered in the experiments. Phosphate may be needed (1) for cereals undersown with seeds because it improves the 'take' of the clovers, and (2) for cereals on newly ploughed-out poor and acid grassland. The latter qualification is, however, contained in the general one that the data refer to average soils and conditions, and that for individual fields

allowance must be made for the soil's nutrient-content as shown by soil analysis, or as estimated by local knowledge and experience.

On the basis of present prices the order of responsiveness to phosphates is potatoes, swedes, mangolds, sugar-beet, cereals. On the basis of starch equivalent, swedes take first place and potatoes second.

Potash.—Potatoes are the most responsive crop, 1 cwt. of sulphate of potash increasing the crop by 18 per cent. in the absence of dung and by 6 per cent. in the presence of dung. Swedes and mangolds are somewhat less responsive and sugar-beet gives only a small percentage response in roots, total sugar, and tops. Potash increased the sugar percentage by a small fraction of 1 per cent., but the corresponding cash return was small.

On the basis of both prices and starch equivalent the order of responsiveness is potatoes, swedes, mangolds, sugar-beet, cereals.

Salt.—Agricultural salt, of which, by complete contrast with potash, this country has vast deposits, has given good responses on both mangolds and sugar-beet, especially when neither dung nor potash was used. The responses of mangolds to 4 cwt. salt were as follows:

	Without dung		*With dung*	
	Without potash	*With potash*	*Without potash*	*With potash*
Response (tons) .	3·4	2·7	2·7	1·8
No. of experiments .	33	24	79	58

In 1940 a series of 24 sugar-beet experiments on representative soils gave the following average yields in tests on 2½ cwt. muriate of potash and/or 5 cwt. of salt per acre, in the presence of a basal dressing of 4 cwt. of sulphate of ammonia.

	Washed roots, tons per acre		*Total sugar, cwt. per acre*	
	No potash	*Potash*	*No potash*	*Potash*
No salt . . .	11·3	12·1	42·3	45·7
Salt . . .	12·5	12·6	47·1	47·6

Used separately salt and potash gave good responses, the response to salt being slightly greater than that to potash. In the presence of salt, potash had a negligible effect, but in the presence of potash, salt still gave a profitable return.

Dressings of from 3 to 5 cwt. salt per acre are suitable and should be applied some time before sowing to reduce risk of delayed germination. The value of the sodium chloride in 30 per cent. potash-salt explains why this form was recommended in the past for sugar-beet and mangolds.

Interactions.—In the previous sections the responses to the different artificial fertilizers have been discussed separately, with the implied assumption that their effects are independent. In reality the situation is more complicated, the response to each fertilizer being influenced to a greater or less extent by the level of the other fertilizers. Such effects are called interactions.

Interactions are of two kinds:

(*a*) One fertilizer may enhance the effect of another (positive interaction), as commonly happens with radically different fertilizers, such as nitrogen, phosphate, and potash.

(*b*) One fertilizer may reduce the effect of the other (negative interaction), as commonly happens when both fertilizers provide the same plant-nutrient. The interactions between dung and phosphate and between dung and potash are illustrations of negative interactions. Occasionally negative interactions occur between radically different fertilizers, but such effects are rare.

Unfortunately most of the experiments under review furnish no clear estimates of these interactions, but a sufficient number of modern experiments on potatoes and sugar-beet have now been completed to show that the interaction effects are somewhat complicated, and also vary from crop to crop. With sugar-beet there is a definite positive interaction between nitrogen and potash, and some indication of a similar but smaller interaction between nitrogen and phosphate. There is little interaction between potash and phosphate. With potatoes there are positive interactions between nitrogen and phosphate, and between phosphate and potash, but there is little interaction between nitrogen and potash.

Like the responses to the different fertilizers, the interactions vary considerably from experiment to experiment, being in general larger when the responses themselves are large. As a general rule it may be taken that there will be little interaction involving any fertilizer which does not itself produce a good response. This is, of course, what might be expected. On general grounds a crop is likely to respond less well to any nutrient component if the other nutrient components are inadequately supplied.

The existence of interactions is commonly used as an argument in favour of properly balanced mixtures or compound fertilizers, adjusted to the needs of individual crops, but applied regardless of soil. The point that is overlooked by the advocates of the uncritical use of such mixtures is that the soil may itself furnish adequate supplies of one or more of the nutrients, in which case there will only be small direct responses to these nutrients, and equally there will be little interaction involving them. The main practical merit of these compound fertilizers lies in the fact that they supply in a convenient form some of each of the three leading plant-foods, and thus cover the risk that any one of these foods may be more deficient than the others. Any widely used compound manure caters for average soils over a wide range of conditions, and to use it is to assume that one's own soil has no special peculiarities which could be met more economically.

With increasing use of the results of field experiments and soil analysis it will be possible to adjust the amounts of phosphate and potash fertilizers more closely to the needs of individual farms and fields. Under peace conditions it was perhaps justifiable to pay somewhat heavily for covering the risks of unsuspected shortages in the hope of building up reserves of plant-nutrients in the soil, but under war conditions it is most

important to adapt manuring much more closely to individual soils, and to 'cash in' on such reserves as do exist. Some fertilizers which are in short supply are necessarily expensive, and it is wasteful for both farmer and nation to use them where they are not in fact needed. It would have been foolish, for example, as is shown in the discussion on optimal dressings, to spread the restricted supply of potash over a wide area of land by a proportionate reduction of the potash-content of all the usual compound fertilizers. Instead, potash has been restricted to certain priority crops, notably potatoes, and to soils known to be deficient in potash. Compound manures for other crops and soils are thus rightly

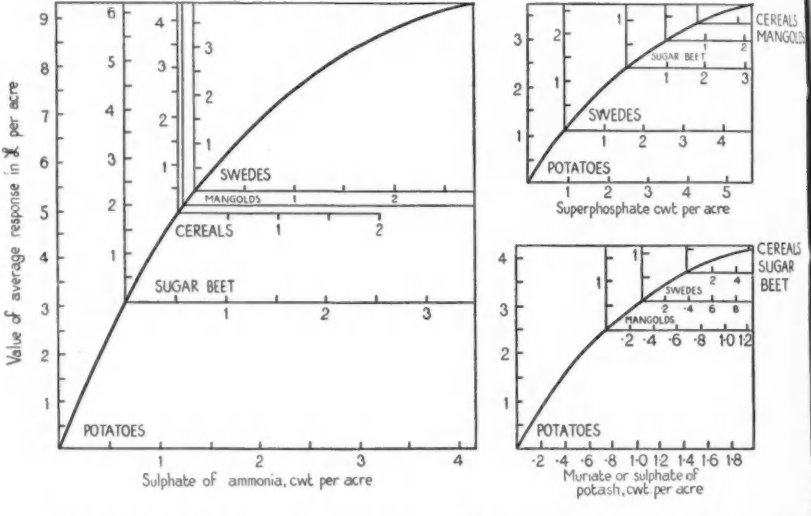

FIG. 1. Value in £ per acre at 1940–1 prices of average responses to fertilizers for root crops grown with dung, and cereals without dung.
(The effects of superphosphate are shown for the West Midlands and North England.)

unbalanced. Similarly, on any but definitely phosphate-deficient soils, it is unnecessary to use phosphates in mixtures for cereals: indeed, most cereals should receive nothing beyond a nitrogenous fertilizer.

Optimal dressings.—When considering how much fertilizer to apply to a crop, the variation in response with varying amounts of the fertilizer must be taken into account. The response to unit weight of any fertilizer falls off as the total amount of the dressing is increased. The exact form of the curve relating amount of dressing and response varies with varying circumstances, but for the purpose of this inquiry it is sufficient to take the standard form described in the Appendix. The curve is illustrated in Fig. 1, which will be explained later.

The most efficient or 'optimal' dressing will be that which gives the maximum financial return after allowing for the cost of the fertilizer and any additional costs resulting from the larger crop. This optimal level

will be reached when the value of the increase in crop resulting from a further small additional dressing is exactly equal to the cost of this additional dressing.

As an example we may consider the optimal dressing of sulphate of ammonia for potatoes grown with dung.[1] The average response to the standard dressing (Table 5) is 0·9 tons. Taking the cost of the standard dressing as 15*s.* per acre and the value of the crop as 110*s.* per ton, we obtain responses and costs as in Table 6:

TABLE 6. *Cash Return from the Use of Sulphate of Ammonia for Potatoes (per acre)*

Dressings of sulphate of ammonia		*Responses*		*Net return*
Cwt.	*Cost*	*Tons*	*Value*	
1·2 (standard)	15*s.*	0·90	99*s.*	84*s.*
2	25*s.*	1·26	139*s.*	114*s.*
3	38*s.*	1·53	168*s.*	130*s.*
4	50*s.*	1·69	186*s.*	136*s.*
5	62*s.*	1·78	196*s.*	134*s.*
6	75*s.*	1·84	202*s.*	127*s.*
7	88*s.*	1·87	206*s.*	118*s.*

The optimal dressing is about 4 cwt. of sulphate of ammonia per acre, but over a wide range around the optimal (from 3 to 6 cwt. per acre) the net profit changes but slightly. Dressings somewhat below the theoretical average optimum will normally be the most attractive to farmers, for the net return will approach the maximum with a lower total outlay than would be required to manure up to the average optimum. But although the profits to the farmer remain fairly steady over a wide range around the optimal, the total production continues to be increased appreciably by manuring to levels well above the optimum.

The dressings which are optimal to the individual farmer will only be optimal from the point of view of the nation if the relative prices of fertilizers and crops accurately represent their relative values to the nation. In deciding these questions it is necessary to consider the alternatives, in terms of costs and shipping facilities, of importing additional food or fertilizers.

Table 7 gives the calculated optimal dressings at 1940–1 prices of crops and fertilizers[2] for root crops grown with and without dung and for cereals without dung.

[1] The method of calculating the optimal dressing directly is described in the Appendix. In this example the value/cost ratio (v/c) is $0{\cdot}9 \times 110/15 = 6{\cdot}6$, and from Table 12 the corresponding optimal dressing is 0·86 cwt. N, or 4·1 cwt. sulphate of ammonia. The value of the increase in crop is $2{\cdot}13 \times 99 - 1{\cdot}58 \times 15 = 187$ shillings, and the net return is $187 - 0{\cdot}86 \times 60 = 136$ shillings.

[2] For simplicity 15*s.* has been taken as the cost of each standard dressing, representing values intermediate between sulphate of ammonia and nitro-chalk, superphosphate and basic slag, and muriate and sulphate of potash, with some allowance for cost of application.

TABLE 7. *Optimal Dressings of Fertilizers*

N = Nitrogenous fertilizer expressed as cwt. sulphate of ammonia per acre.
P = Phosphatic fertilizer expressed as cwt. superphosphate per acre.
K = Potassic fertilizer expressed as cwt. sulphate or muriate of potash per acre.

Optimal dressings

	Great Britain	*S. and E. England*	*W. Midlands and N. England*	*S.W. England, Wales, and Scotland*	*Great Britain*
With dung:	N	P	P	P	K
Swedes	2·7	3·5	4·8	6·5	0·9
Mangolds	2·9	0·8	2·2	3·8	1·2
Sugar-beet	3·5	1·9	3·2	4·9	0·6
Potatoes	4·1	4·3	5·6	7·3	2·0
Without dung:					
Swedes	2·9	5·8	7·1	8·8	1·7
Mangolds	3·0	3·1	4·4	6·1	2·0
Sugar-beet	3·7	4·1	5·4	7·1	1·3
Potatoes	4·3	6·6	7·9	9·6	2·7
Cereals	2·0*	0·1	1·4	3·1	0·1

Average crop responses for above dressings when used without dung

	Roots: tons per acre				
Swedes	3·9	3·3	5·3	9·3	2·6
Mangolds	5·1	1·4	2·5	4·7	4·5
Sugar-beet	1·8	0·6	1·1	2·0	0·6
Potatoes	1·9	1·0	1·5	2·7	1·7
	Grain: cwt. per acre				
Cereals	4·8	0·1	0·6	1·7	0·1

* Arbitrary upper limit.

Many of the optima may seem unduly high, but it is interesting to note that before the war the consumption of nitrogenous fertilizer per acre of arable land was over five times as high in Holland and Belgium and well over twice as high in Germany as in Great Britain.

The most serious discrepancy between optimal and current average rates of manuring is for nitrogen on cereals. From the average responses already given, the calculated optimal dressing amounts to 3·0 cwt. sulphate of ammonia per acre. This quantity might often cause lodging, and an upper limit of 2 cwt. sulphate of ammonia per acre for cereals has therefore been adopted in subsequent discussion. By manuring to this average rate it is estimated that there would be a gross return from the cereals grown on pre-war acreages of about £17,000,000, for nitrogenous fertilizers costing about £6,000,000. If an average of only 1 cwt. sulphate of ammonia per acre for cereals were attained, it would give a return on pre-war acreages of £11,000,000 for an outlay on fertilizer of £3,000,000. In pre-war practice the return was about £4,000,000 for an outlay of about £1,000,000. In a survey of a random selection of farms a few years ago it was found that two-thirds of the farmers failed to give any fertilizer to the grain crops preceding their potatoes.

This discrepancy between the highly consistent results of actual trials in Great Britain, Ireland, and three Baltic countries, and the current practice of British farmers calls for explanation. Fear of lodging is undoubtedly one of the causes. Another probable cause is that farmers have failed to appreciate the fact that under normal conditions cereals require only a nitrogenous fertilizer, applied in the spring either in the seed-bed or as a top-dressing. They may have tried compound cereal manures and been disappointed, without realizing that little return was to be expected from the phosphate and potash. Barley-growers have feared that the nitrogenous fertilizer would reduce the malting quality of their barley, but many experiments have shown that up to 1 cwt. of sulphate of ammonia per acre may safely be used without perceptible effect on malting quality, and even more under favourable conditions. Finally, one of the main factors has been the simple fact that reliable cereal experiments are difficult to conduct and have not therefore been widely attempted in this country.

For roots also the optimal dressings require a greater proportion of nitrogen than is generally used. Thus for potatoes grown with dung in the West Midlands and North England the optimal dressings, as given in Table 7, are 4·1 cwt. sulphate of ammonia, 5·6 cwt. superphosphate, and 2·0 cwt. sulphate of potash per acre, or 0·86 cwt. N; 0·93 cwt. P_2O_5; 1·0 cwt. K_2O. In a random sample of 500 potato farms in 1937 the average amounts of fertilizer in cwt. per acre were 0·36 N, 0·52 soluble P_2O_5, 0·11 insoluble P_2O_5, 0·68 K_2O.

Subject to the general condition that the south and east of England need less and Scotland and Wales more phosphate than the average, it may be said that the optimal requirements for root crops grown with dung are roughly equal amounts of nitrogen, phosphoric acid, and potash, or in a compound fertilizer about equal percentages of N, soluble P_2O_5, and K_2O. Relative to the amount of nitrogen used, swedes require more phosphate, and mangolds and sugar-beet less; sugar-beet also needs less potash. For rates of manuring below the optimal the proportion of nitrogen to the other constituents should be still further increased.

The older types of compound fertilizer generally provide a much greater percentage of phosphoric acid than of nitrogen. In the last fifteen years or so there has been a general tendency to recommend higher proportions of nitrogen and potash in potato mixtures, as a result of experiments, first at Kirton and then at various centres by the Rothamsted staff, which showed that many potato-growers were using uneconomically high amounts of phosphate.

In the aggregate the pre-war consumption of superphosphate on arable land was a reasonable fraction—around two-thirds—of the estimated optima for the acreage, but there can be little doubt that its distribution among crops and between soils was far from ideal. Some of the reserves built up by heavy phosphatic manuring in the past can be utilized in war-time on certain classes of soils, but it must be remembered a large fraction of the phosphate added to soils is unavoidably lost by its conversion into unavailable forms, especially on acid soils. In this

connexion it must also be remembered that not only will newly ploughed-out grassland on acid soils need lime and phosphate to fit it for arable crops, but that the phosphatic dressings will have to be repeated more frequently than would be customary for arable land in good heart.

The outstanding need for potash is clearly that of potatoes. We have estimated that even at the actual current rates of application about 70 per cent. of the total return for potash among the field crops here considered comes from potatoes. The immediate problem is not to increase the dressings to the optimal but to make the best use of a decreasing supply. For this purpose it is essential that a still larger proportion of the total available potash should find its way to the most responsive crop—the potato—and not be disseminated over crops indiscriminately through an undue belief in the virtues of balanced fertilizers.

Effects of changing supplies.—At the present time both the country as a whole and the individual farmers are faced with the problem of adjusting fertilizer allocation among various crops and among different districts or fields in such a way as to secure the biggest output from changing supplies. Potash supplies are already short; other fertilizers manufactured in this country and formerly exported may be available in larger quantities, though occasions may arise either in districts or on individual farms when farmers cannot obtain all they require. It is necessary therefore to have some sound key to the problem of making adjustments, rapidly if need be.

The maximum financial returns from a fertilizer on an average farm or throughout the country will be greatest when each crop receives its optimal dressing. With smaller supplies of a fertilizer the greatest returns will be obtained when the total amount on a farm or throughout the country is distributed so that the *dressings for all crops are reduced by the same amount below their optimal dressings*. The reduction should not be a proportionate one.

By subtracting suitable constant amounts from the values for the optimal dressings given in Table 7, a series of rates for the different crops can be obtained, and these can be used in conjunction with the acreages of the crops to determine the best distribution of a fertilizer on a farm. In the case of superphosphate, for example, the best allocation among crops at different levels of total supply can be obtained by trial from the figures set out in Table 8 (where reductions by steps of 1·5 cwt. per acre are made), multiplying the acreages of the various crops by their requirements. The last column shows the results of such a calculation for a farm with the acreages shown in the last line of the table.

If the farmer wishes to allocate 10 tons (200 cwt.) of superphosphate, he should apply amounts of fertilizer intermediate between those given in lines 3 and 4 of the table. As the theoretical dressing for mangolds is very small, no superphosphate need in practice be applied to this crop or to the cereals. The allocation between crops might therefore be as follows: swedes, 5 cwt. per acre; sugar-beet, 3½ cwt. per acre; potatoes, 4 cwt. per acre.

Such an allocation is, in fact, the common practice of many farmers at the present time, for they give most or perhaps the whole of their phos-

phate and potash to the root crops, especially swedes and potatoes, and restrict the manuring (if any) of their cereals to a nitrogenous top-dressing.

TABLE 8. *Optimal Requirements of Superphosphate in cwt. per acre at Varying Levels of Total Supply, with an Example for a Single Farm*

O = without dung. D = with dung.

Optimal dressings for:	*Swedes*		*Mangolds*		*Sugar-beet*		*Potatoes*		*Cereals*	*Example: Total Super-phosphate required (cwt.)*
	O	D	O	D	O	D	O	D	O	
Scotland, &c.	8·8	6·5	6·1	3·8	7·1	4·9	9·6	7·3	3·1	693
W. Midlands, &c.	7·3	5·0	4·6	2·3	5·6	3·4	8·1	5·8	1·6	468
S. and E. England	5·8	3·5	3·1	0·8	4·1	1·9	6·6	4·3	0·1	243
	4·3	2·0	1·6	..	2·6	0·4	5·1	2·8	..	151
	2·8	0·5	0·1	..	1·1	..	3·6	1·3	..	61
Example: acreage of crops on farm	10	..	..	10	20	..	..	20	90	

These relationships between the different crops are illustrated in Fig. 1, which shows the response-curves for roots with and cereals without dung, arranged so that equally efficient dressings are vertically above one another. The extreme right of the diagram shows the optimal dressings. From these curves the average response for any dressing can be read off. Equal reductions below optimal dressings cause equal reductions below optimal returns, because the response-curves for various crops are in fact part of the same curve, once crop and fertilizer prices have been fixed.

TABLE 9. *Fertilizer Mixtures for Potatoes at Varying Costs (W. Midlands and N. England)*

Cost of fertilizer mixture per acre	*With dung*			*Without dung*		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	cwt. per acre			cwt. per acre		
£ s. d.						
6 15 0	..	..	..	0·91	1·32	1·37 (optimal)
5 10 0	0·87	0·94	0·99 (optimal)	0·73	1·08	1·13
4 5 0	0·69	0·70	0·75	0·56	0·84	0·89
3 0 0	0·52	0·46	0·51	0·38	0·59	0·64
1 15 0	0·35	0·21	0·26	0·21	0·35	0·40

To obtain the best mixture of fertilizers for a given outlay the rule is that *the reductions below optimal should be in the ratios* $N:P_2O_5:K_2O$ *as* 1:1·38:1·38 or sulphate of ammonia: superphosphate: sulphate of potash as 1:1·7:0·6. This rule is illustrated in Table 9 where the best mixtures for potatoes in the West Midlands and North of England are set out.

For potatoes grown with dung in West Midlands and the North of

England the best ratios of $N:P_2O_5:K_2O$ at all levels of manuring do not differ widely from 1:1:1, i.e. equal percentages of these three nutrients in terms of the statutory fertilizer analysis. For potatoes grown without dung the proportions of P_2O_5 and K_2O should be higher. It happens that the average pre-war dressing for potatoes agreed very closely in amount and proportions with the £3 per acre dressing for potatoes grown without dung, but the bulk of the potatoes were, in fact, grown with dung, and a greater proportion of nitrogen should therefore have been used.

At the present time, when synthetic nitrogenous fertilizers are being produced in this country and potash is scarce, the balance should be adjusted still further in the direction of higher nitrogen and lower potash. The war-time concentrated fertilizer containing potash provides equal percentages of N and P_2O_5 with a lower proportion of K_2O, and is therefore suitable for potatoes grown without dung. For potatoes grown with dung some of the concentrated fertilizer may well be replaced by sulphate of ammonia.

Many potato compound fertilizers contain much too low a proportion of nitrogen. One quoted in the market returns for December 1940 has the following percentage analysis: 3·5 N, 10·5 soluble P_2O_5, 1·4 insoluble P_2O_5, 5·0 K_2O. Such a mixture should be reinforced by sulphate of ammonia to raise the amount of nitrogen to approximate equality with that of soluble phosphoric acid.

The rates of application mentioned, of course, refer to average conditions. They may be modified for individual fields and farms in the light of former experience or soil analysis, but even these modifications should take the form of a constant amount subtracted from or added to the optimal dressings for individual crops. Poor soils or those with special deficiencies must, of course, receive extra amounts of the appropriate fertilizers.

From the national point of view the best aggregate return for a given amount of fertilizer will be obtained when all farmers with land of average fertility are working to about the same rate below the optimal dressings. If some farmers give larger dressings and others little or no fertilizer, the total returns will be considerably less. Thus, for example, if two acres of potatoes received a dressing of 0·4 cwt. N per acre, the total increase in yield may be expected to be $2 \times 1{\cdot}36 \times 0{\cdot}9 = 2{\cdot}45$ tons, whereas if 1 acre receives 0·8 cwt. N and the other is unmanured, the expected increase is $1{\cdot}85 \times 0{\cdot}9 = 1{\cdot}66$ tons, i.e. a reduction of 32 per cent. If the dressings are 0·2 cwt. N on 2 acres or 0·4 cwt. N on 1 acre, the corresponding reduction is 20 per cent.

Actual and Optimal Consumption of Fertilizers in Great Britain

For those concerned primarily with aggregate totals for the country as a whole, the figures already given can be built up to totals by using crop acreages and by making certain assumptions about the proportion of each crop in the three main districts which normally receives dung. Table 10 shows the gross and net values of the crop increases likely to be obtained in a normal season from the optimal rates and also from

various general levels below their optima. This Table was calculated for acreages of each crop equal to those of 1937. It gives the total amounts of fertilizer elements required for these acreages and also for additional acreages of potatoes and cereals, assuming that the additional land had the same requirements as old arable land without dung in the West Midlands and North.

TABLE 10. *Crop Increases due to Optimal and Sub-optimal Fertilizer Dressings*

	Pre-war acreages. Increased value of crops Million £		*Total consumption for pre-war acreages*	*Consumption per additional million acres*	
	Gross	Net		*Potatoes*	*Cereals*
NITROGENOUS FERTILIZER (as N)			*1,000 tons N*		
Optimal rates	29·2	19·4	163	46	20
" " less 0·2 cwt. N per acre	27·7	19·1	144	36	20
" " " 0·3 " "	24·2	17·4	114	31	16
" " " 0·4 " "	19·3	14·5	80	26	11
" " " 0·5 " "	*13·1*	*10·2*	*47**	21	6
PHOSPHATIC FERTILIZER (as P_2O_5)			*1,000 tons* P_2O_5		
Optimal rates	8·9	5·0	131	66	12
" " less 0·15 cwt. P_2O_5 per acre	7·7	4·8	95	58	4
" " " 0·2 " "	*7·1*	*4·6*	*80**	56	..
" " " 0·3 " "	6·3	4·3	65	51	..
" " " 0·45 " "	5·1	3·8	43	44	..
POTASSIC FERTILIZER (as K_2O)			*1,000 tons* K_2O		
Optimal rates	5·4	3·1	78	68	2
" " less 0·1 cwt. K_2O per acre	*4·7*	*3·0*	*59**	63	..
" " " 0·25 " "	4·2	2·9	44	56	..
" " " 0·5 " "	2·9	2·2	23	44	..

* Approximately equal to pre-war consumption.

In each section of the Table one rate of application has been marked as approximating to the pre-war total consumption of fertilizers on arable land, but the returns from the pre-war use of fertilizers were undoubtedly less than those calculated from the ideal distribution of fertilizers between crops. In the absence of information from representative surveys of the way in which farmers actually used their fertilizers, it is impossible to make a reliable estimate of the returns they attained. Under war conditions, when it is of vital importance to increase efficiency of production to the utmost, such a survey would be of the greatest value.

Table 10 shows that by increasing the use of sulphate of ammonia by 1 cwt. per acre, with a proper distribution between crops, the total additional output of crops from the pre-war acreage would be worth £11,000,000 for additional fertilizer costing £4,000,000. Of the additional nitrogen, by far the greater part would be used for cereals. Most of the newly ploughed land will need nitrogenous fertilizer, at least after the first season, and the expanded acreages, together with the need for heavier dressings all round, require a vast increase in the total consumption. In view of possible temporary shortages through difficulties of distribution during the spring fertilizer season, it may be pointed out that good results are obtained from late applications of nitrogenous top-dressings to cereals, and that there is evidence that a divided dressing

—half in early spring and half quite late—is better than the whole applied at either time.

As far as phosphate is concerned, apart from a modest all-round increase for root crops, the main needs are for a better adjustment to the requirements of individual soils, including, of course, much of the newly ploughed-up grassland which is particularly deficient in phosphate. A large increase in the potato crop will necessitate a correspondingly great increase in the use of superphosphate. The figures given in Table 10 for phosphate requirements on new land are definitely underestimates, as they were derived from average potato crops mainly on old arable land.

The potentialities of increase in the use of potash would be much less than for the other two classes of fertilizer even if extra supplies were available. Pre-war consumption in the aggregate was approaching optimal, though there was, of course, great opportunity for closer adjustment to the needs of individual soils. With greatly reduced supplies all other crops must be sacrificed to ensure a sufficiency, first for potatoes, and then for other roots, such as swedes and mangolds. (Market-garden crops, which are omitted from this discussion, also stand in high need of potash.) The potato crop must receive all available supplies both directly as fertilizer and indirectly through farmyard manure and other forms of crop residues and vegetable wastes. It is important to exploit to the full the hidden reserves of soil potash by concentrating potatoes on land likely to have reasonable reserves from previous manuring, and by avoiding the disappointments and waste of effort which must result if potatoes are grown without potassic fertilizers on soils particularly deficient in potash. The estimation of soil reserves by analytical methods is important not only for the proper distribution of fertilizers but for the sound allocation of crops to secure the maximum utilization of the reserve fertility of our soils.

APPENDIX

The form of response-curve adopted in this paper is

$$y = y_0 + d(1 - 10^{-kx}),$$

where y is the yield with a fertilizer dressing of x cwt. N, P_2O_5 or K_2O per acre, y_0 the yield with no fertilizer, d the limiting response, and k a value assumed to be constant for each of the three principal classes of fertilizer. The form of the curve implies that the response $(y_1 - y_0)$ to a unit dressing of amount p of a fertilizer bears a constant ratio, 10^{kp}, to the additional response to a second unit. The latter response bears the same ratio to the further additional response obtained by the application of a third unit.

From various series of British experiments the following average values were obtained: $k_N = 1{\cdot}1$, $k_P = 0{\cdot}8$, $k_K = 0{\cdot}8$, $k_{Dung} = 0{\cdot}04$ (for sugar-beet tops k_N was taken as $0{\cdot}4$). A later analysis of a much larger number of experiments in Sweden and Denmark confirmed the general accuracy of these values, though it suggested that some further improvement would be obtained by giving k_N a slightly higher value for cereals and a slightly lower one for roots. The values for k_P and k_K are in reasonable agreement with the corresponding constants used by Mitscherlich, but his value for nitrogen is quite inappropriate for field experiments.

The relative responses to different dressings are shown in Table 11, the response

to the standard dressing being taken as unity. In order to convert the response to any given dressing to standard it is only necessary to divide by the value of the relative response corresponding to that dressing.

TABLE 11. *Standard Response Curves for N, P, and K*

N ($k_N = 1{\cdot}1$)		*P and K* (k_P and $k_K = 0{\cdot}8$)	
Cwt. N per acre	*Relative response*	*Cwt. P_2O_5 or K_2O per acre*	*Relative response*
0·1	0·48	0·2	0·51
0·2	0·85	0·4	0·87
0·25	*1·00*	*0·5*	*1·00*
0·3	1·14	0·6	1·11
0·4	1·36	0·8	1·28
0·5	1·53	1·0	1·40
0·6	1·67	1·2	1·48
0·7	1·77	1·4	1·54
0·8	1·85	1·6	1·58
0·9	1·91	1·8	1·60
1·0	1·96	2·0	1·62

If the standard response curves are accepted as correct, the optimal dressings (in cwt. N, P_2O_5, and K_2O per acre) are:

For N . . . $0{\cdot}12+(\log v-\log c)/1{\cdot}1$,
For P_2O_5 and K_2O . $0{\cdot}23+(\log v-\log c)/0{\cdot}8$,

where v is the value per acre of the response to the standard dressing, and c is the cost per acre of that dressing. Table 12 shows the optimal dressings corresponding to a series of value-cost ratios, v/c.

TABLE 12. *Optimal Dressings for Various Values of v/c*

	Optimal dressing in cwt. per acre of	
v/c	*N*	*P_2O_5 or K_2O*
1	0·12	0·23
1·5	0·28	0·45
2	0·39	0·61
3	0·55	0·83
4	0·67	0·98
6	0·83	1·20
8	0·94	1·36
10	1·03	1·48

The gross values of the responses to the optimal dressings are:

For N . . . $2{\cdot}13v-1{\cdot}58c$.
For P_2O_5 and K_2O . $1{\cdot}66v-1{\cdot}09c$.

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ON MEASURING THE EFFICIENCY OF A TRACTOR BY ITS FUEL CONSUMPTION

E. W. RUSSELL AND H. J. HINE

(*Soil Physics Department, Rothamsted Experimental Station, Harpenden, England*)

TRACTOR-TESTING has so far normally been carried out at tractor-testing laboratories using elaborate and costly equipment which cannot be generally available to most agricultural research stations. Research stations without this specialized equipment may have problems presented to them which involve making reasonably accurate measurements of tractor performance. As an example this Station was asked to investigate how the performance of a tractor carrying out normal agricultural operations depended on the type of driving-wheel used, and in particular to determine the advantages and limitations of pneumatic tyres on a tractor. One of the methods used has given such promising results that it is hoped it will allow other laboratories to undertake research on the field performance of tractors.

The information needed by a practical farmer when discussing tractor performance is first: will the tractor do the work satisfactorily, and if it will can the efficiency of the tractor be increased either by increasing the speed of work or by reducing the fuel consumption or by reducing its rate of depreciation. The investigations made considered only the first two ways of increasing tractor efficiency and perforce had to ignore the third entirely. In particular, it is the object of this paper to describe the methods used for comparing the fuel consumption of the tractor under different conditions of work.

The principle underlying the method employed is already widely adopted in agricultural field trials, namely, to determine not only the treatment mean, the mean fuel consumption in the present case, but also its standard error, so that it is possible to judge if the differences between the mean fuel consumptions obtained when the tractor is working under different conditions can reasonably be ascribed to the different conditions of work or only to mere chance fluctuations.

The first stage in the method consists in measuring the fuel consumption of the tractor over a series of short runs instead of one or two long runs. This should allow an estimate to be made of the variability or the error of the mean, which is unconnected with the factor being investigated. And this condition is vital to the subsequent interpretation of the data. It is, therefore, essential to ensure as far as is possible that the fuel used during all the measurements on one tractor condition is not systematically higher or lower than on another tractor condition for reasons unconnected with that treatment. As an example, suppose the tractor is ploughing and a comparison is being made between the fuel used when the tractor is running with the engine-governor full open and only half open. If all the runs with full governor are made first, and if the soil is gradually becoming heavier to plough for any reason, then it

would appear that the fuel efficiency of the tractor when running with full governor was higher than with half governor, but there would be no way of knowing how far this was due to the ploughing conditions being easier.

The second stage in the method consists in allowing for the effect of any measurable factors affecting the fuel that are unconnected with the factors under investigation. It also often allows one to mitigate the harmful effects of systematic errors of the type mentioned above.

Measurements taken.—In all the experiments described here a Case tractor model C modified CC has been employed, and it has either been ploughing or cultivating. Petrol has been the fuel used throughout. A small auxiliary petrol-tank was fitted to the tractor and the fuel supply went through a two-way tap so that petrol was entering the carburettor either direct from the main petrol-tank when the tap was in one position, or from the auxiliary petrol-tank when it was in the second position. The auxiliary petrol-tank was of brass and was closed on top by a cup which was joined to the tank by a neck about $\frac{1}{4}$ in. in diameter. Petrol was poured in the tank until it came up to the top of the neck. A small brass tube, open to the air, was fitted to the tank just below the neck to allow air to escape without having to blow through the neck. At the side of the tank was an open protected glass tube, of internal diameter $\frac{9}{32}$ in., so that the approximate petrol-level in the tank could be seen.

A run is made in the following way. The engine is warmed up, all paraffin is flushed out of the fuel system and the engine is left running on petrol from the main tank. The auxiliary tank is filled up to the top of the neck. The tractor starts work and when it comes to the beginning of its measured course the two-way tap is turned over so that the engine runs on the auxiliary tank. This tank is then turned off at the end of the course, the tractor is then stopped and petrol from a graduated glass measuring-cylinder is poured into the tank until it comes up to the top of the neck. The amount of petrol so measured is taken to be the amount used during this measured run. It is very important that the tractor should be properly warmed up before the experimental runs start. Not only must the engine be warm but it seems as if the gear-box needs to be used as well. If this precaution is not taken, the first one or two fuel consumptions may be 10–20 c.c. too high, which, on a 200 c.c. run, a fairly typical example, is a serious error.

During a run the following measurements were also taken: the time of the run and the number of revolutions of the land driving-wheel if the tractor were ploughing, or of one of the driving-wheels if it were cultivating. If a third person was present the number of revolutions of the other driving-wheel was also counted. The mean drawbar-pull exerted by the tractor was also always estimated. Two types of dynamometer were tried, both designed and made by the Institute of Agricultural Engineering, Oxford. The first one had a dial on the dynamometer, so that the tractor driver had to keep looking backwards to read it. The second had a pressure-gauge mounted on the tractor in front of the driver. Both types had a device for regulating the damping, and by keeping the gauge reasonably damped it was quite easy to take a reading.

Actually, in all the work the driver's estimate of the mean drawbar-pull was used. The errors introduced by using his estimate will be shown, in the last section of this paper, not to reduce appreciably the accuracy of the final results, and the small loss of accuracy incurred is more than counterbalanced by the great saving of time over measuring up dynamometer charts.

Statistical methods used.—The results obtained by the methods described in this paper are only valid so long as the experiments have valid statistical designs, for these control the validity of the arithmetical calculations needed to extract the required information from the experimental data. The statistical principles that must be observed are described in detail in several publications dealing with agricultural field trials, as well as in Fisher's book on the subject,[1] and, when applied to experiments of the type being considered here, are not onerous. The statistical methods of analysis needed are the analyses of variance and co-variance, and at times multiple regression, and these again are adequately described in many modern publications. For the benefit of non-statistical readers a short description of the purpose of the statistical methods used is given here.

The purpose of the analysis of variance alone is to remove the contributions that the presence or absence of certain definite factors makes to the variations in the quantity being measured, so that the precision of the measured mean is increased. It allows one at the same time to estimate the probability that these factors do in fact influence the variability of the measured quantity. For example, if the fuel consumption of a tractor ploughing up and down a slope is being measured, the application of the analysis of variance allows one to decide if the hill affects the fuel consumption and, if it does, to remove its effect from the variability of the observed fuel consumption, so decreasing the standard error of the observed mean. This removal of the effect of the hill on the variability of the mean fuel consumption does not imply that this mean fuel consumption is the same as would be found if the tractor was ploughing on the level, and this illustrates why the exact significance of the mean must be carefully considered before it is used for further comparisons. In this particular example, as will be shown later, the mean fuel consumption when ploughing up and down a uniform slope does in fact appear to be the same as when ploughing on the level, but this is a fact of experiment and has nothing to do with statistical analysis, though the analysis is essential to increase the precision of the truth of the statement that these two means do not in fact differ significantly.

The analysis of co-variance enables allowance to be made in the quantity under examination for uncontrolled variations in one or more of the associated measurements by obtaining the regression equation connecting them with this quantity, and then adjusting the mean value of this quantity to its expected value had the associated variables been held constant. For example, if the effect on fuel consumption due to varying the type of driving-wheel fitted to a tractor is being studied, the

[1] *The Design of Experiments*, by R. A. Fisher. Oliver and Boyd, Edinburgh.

mean drawbar-pulls in the different experiments will not in general be the same, on account of the heterogeneity of the soil being ploughed. If there is a reasonably close relationship between the fuel consumption and the drawbar-pull, the accuracy of the comparison of the types of wheels will be increased by using this method to adjust the mean fuel consumption for each wheel to the value it would be expected to have if the drawbar-pull had been kept at its mean value throughout the experiment.

There is an important limitation to the class of subsidiary measurements which may be used to increase the precision of the main comparisons in this way. In the example above, the treatment described is appropriate only if the differences in drawbar-pulls for the several types of wheel are the result of mere random variations in the character of the ground being ploughed, and are not themselves caused by the differences in wheels. If an analysis of variance of the drawbar-pulls, on exactly the same plan as for the fuel consumptions—the computation of which is, incidentally, an essential part of the co-variance analysis—shows that there were significant differences in the mean drawbar-pulls corresponding to the different types of wheel, any adjustment of the fuel consumption to a basis of *equal* drawbar-pulls would prove misleading and should not, in general, be attempted. In the particular example given it has in fact been assumed that the draught of the plough is independent of the type of tractor wheel fitted, as it was not possible to test this by controlled experiment. But the only likely cause of dependence is the speed of ploughing, and the draught has been shown to be independent of this within the experimental range. It is highly probable, therefore, that it is legitimate to increase the accuracy of the comparisons of the fuel consumptions by making them at equal drawbar-pull. On the other hand, the time taken to plough a given distance will, in general, be directly affected by the type of wheel used, since different types have different rolling radii and may give different amounts of slip. Hence if the fuel consumptions were adjusted for inequalities in the time of ploughing, one of the most important components of the wheel effect might be removed and possibly a conclusion reached that two tyres were equally efficient when in fact one was better on account of its allowing the tractor to move at a greater speed.

Accuracy of the fuel measurements.—Accuracy of fuel measurement depends upon three separate factors: (i) the accuracy of the actual measurement of the quantity of fuel used, which is solely dependent upon the accuracy of the difference between the two readings of the measuring-cylinder and the accuracy with which the auxiliary petrol-tank can be filled up to a standard condition; (ii) the effect of the variable tilts the tractor may have in the field when the auxiliary fuel-tank is being filled up on the capacity of the tank; and (iii) the constancy of fuel used by the tractor-engine when the tractor is running under constant conditions.

A few experiments have been made on the accuracy with which the tank can be filled from the measuring-cylinders used, which were usually 500 c.c. glass cylinders graduated in 5 c.c. divisions, and on the

influence of tractor tilt. It was found that fuel measurements could be in error by about 1·2 c.c., due to errors of measurement alone, which was increased to about 1·6 c.c. when errors of tilt were superimposed. There has been no opportunity of determining the order of magnitude of the third factor by running the tractor under accurately controlled conditions, as no testing car was available.

Estimates can be made from the results of actual runs of the upper limit of the errors of measurement by calculating the variability of the fuel consumption of the tractor ploughing a measured course when variations in drawbar-pull and time of run are allowed for. It was not necessary for the investigations (for which this technique was developed) to find out by how much this upper limit is in excess of the actual errors of measurement, but it is in excess since there is no reason to suppose that all the effects of the soil and plough variabilities on the fuel consumption have been eliminated by the multiple regression of the speed and drawbar-pull on fuel consumption.

Two examples will be given to show the kind of accuracy of fuel measurement obtained. In the first one the tractor was ploughing a field having a pronounced unsymmetrical ridge running across the direction of ploughing, though the levels at the beginning and end of the run were probably about the same. The tractor pulled a three-furrow plough easily over most of the field in second gear, the mean drawbar-pull was about 1,600 lb., and the mean speed about 3¾ miles per hour. The field was not very uniform, the mean pull over the 8-chain[1] course varied from about 1,300 to 1,900 lb., with a large variation of pulls in each run. The mean fuel consumption for the 8-chain run was 256 c.c. In the second example the tractor was again ploughing up and down a slope, but as the mean drawbar-pull was 1,900 lb., the ploughing had to be done in first gear. The ground was very hard wheat-stubble, the soil a stony clay, and the fuel consumption was measured for a 5½-chain course. The mean speed of ploughing was 2½ miles per hour and the mean fuel consumption 229 c.c. for the 5½-chain run.

Table 1 gives the results for the various stages of carrying out these calculations. The first row of the table gives simply the standard errors when no corrections whatever are made for the variability of the soil or the field. The second row gives the standard errors of the actual fuel consumption from the values calculated from the regression of time and drawbar-pull, and the third row gives the standard error after allowance has been made for the effect of slope.

TABLE 1. *Estimated Standard Error of Fuel Consumption (in c.c.)*

Soil	Sandy, loose	Stony clay, hard
Tractor gear	Second	First
Uncorrected standard error	21·3	18·4
Corrected for the regression of time and mean drawbar-pull	6·1	8·7
Corrected for slope of ground as well	5·5	5·6

Both these examples show that in practice the fuel is measured with

[1] 1 chain = 22 yards = 20·12 metres.

a standard error of 5½ c.c., or about 2–2½ per cent. Standard errors of lower absolute, though of somewhat larger proportional, amounts are obtained on shorter runs, as is shown in the experiment on which Fig. 1 is based.

Relationship between fuel consumption and drawbar-pull.—An example will serve to show the kind of relationship between the fuel consumption of the tractor and the drawbar-pull. The tractor fitted with 11·25 × 28-in. pneumatic tyres was working in first gear and was drawing a culti-

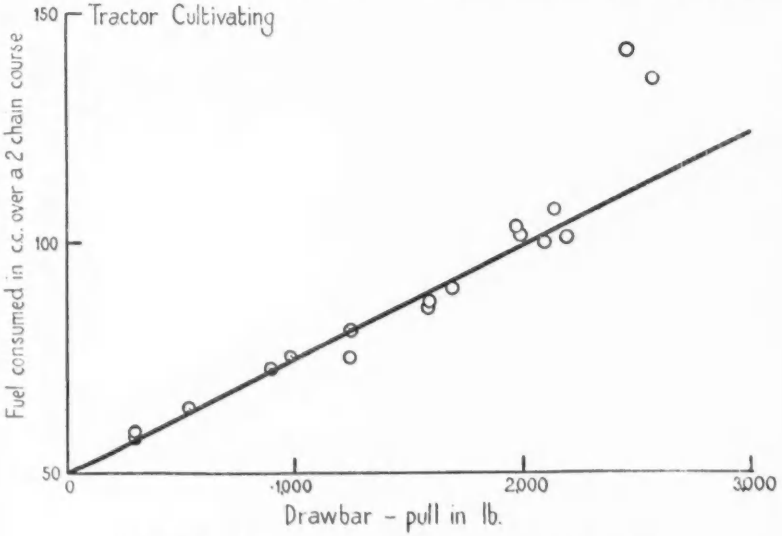

FIG. 1. The relation between fuel consumption and drawbar-pull.

vator through the soil. The fuel consumed to draw the cultivator over a 2-chain course and the mean drawbar-pull were measured, the cultivator was then set either deeper or shallower and a new run was made, and so on. The time was December, the soil was loose and wet, and when the load became too heavy the tractor wheels spun round and the tractor dug itself in. But before this happened the fuel consumption rose abnormally. Fig. 1 shows the result of a typical experiment. The straight line has been fitted to all the experimental points except the last two by the method of least squares. The root mean-square deviation of these points from the line is 3·0 c.c., but the neglected points come 20 and 30 c.c. above the line.

This example shows that the fuel consumption increases linearly with the drawbar-pull from zero pull up to the point at which it increases suddenly either because the engine or the wheels are overloaded, and no exceptions have yet been found for this result. It also shows up the limitation of the method described, for the fuel consumption can be corrected for drawbar-pull only when all such high readings are omitted from the calculations.

This example also gives an answer to the argument that fuel measurements are an inefficient way of estimating the efficiency of the tractor doing a given job because the tractor uses so much fuel when running light that large differences in the efficiency of the tractor when working have only a small effect on the fuel consumption. The argument can be seen to have only a certain measure of validity. Fuel measurements are an inefficient way of comparing the efficiency of a tractor working under different conditions if it is working only at a fraction of its rated horse-power and the wheels are gripping properly. But under these conditions small differences in the tractor efficiency have usually little practical importance. The differences become of practical importance only when they do begin to have an appreciable effect on the fuel consumption or on some other easily measurable factor, such as slip or speed.

Reproducibility of the fuel measurements.—Two sets of data are available to show the kind of reproducibility obtained in these experiments. The first was for a field on a sandy loam at Woburn, Beds., where the fuel consumption was measured when the tractor was working in second gear and drawing a three-furrow plough over an 8-chain course. The moisture-contents of the soil at each date were not recorded, but the firmness of the surface was probably about the same. The fuel consumptions reduced to a constant drawbar-pull of 1,345 lb. were:

Date	*Fuel in c.c. per 8 chains*	*Difference from mean*	*Standard error of difference*
29/5/40	253·3	−2·4	3·4
11/6/40	250·9	0·0	2·5
27/6/40	248·4	2·5	2·7
Mean	250·9	..	..

The gradual fall in the mean is probably without significance, for if the first and the last experiments are considered the difference in fuel consumption is $4{\cdot}9 \pm 4{\cdot}0$ c.c.

The second set was made on Broadbalk field at Rothamsted. The soil is a stony clay; the surface was wheat-stubble and was extremely hard and dry on August 28–30, was wet on October 9–10, and was intermediate in the middle of September. The tractor was working in first gear and was drawing a three-furrow plough over 5-chain and 5½-chain courses. The fuel consumptions per chain, adjusted to a drawbar-pull of 1,910 lb. in c.c. per chain, were:

Date	*Fuel per chain in c.c.*	*Difference from mean*	*Standard error of difference*
28–30/8/40	41·10	−0·73	0·39
11–12/9/40	42·42	0·59	0·50
13–18/9/40	42·05	0·22	0·34
9–10/10/40	41·75	−0·08	0·77
Mean	41·83	..	..

The high standard error of the experiments of October 9–10 is due to the fact that only two 5½-chain and two 5-chain runs were made on that

day, whereas on the others usually 16–20 runs in all were made. If this last run is ignored it is seen that there is a significant difference between the August and September runs of 1·13±0·39 c.c., possibly due to the drier surface in August. This shows the kind of constancy one gets when the determinations are made over an extended period of time.

Sensitivity of the fuel measurements.—Two examples will be given to show that the fuel consumption is sensitive to soil conditions. The first one shows the effect of the slope of the ground. Broadbalk field has a mean slope of 1 in 25 for the bottom 5½ chains and of 1 in 110 for the top 5 chains. All the fuel consumptions have been adjusted to a drawbar-pull of 1,950 lb., the mean for this experiment, because in this experiment there was no connexion between the drawbar-pulls and the directions of ploughing.

	Slope: 1 in 25		*Slope: 1 in 110*		
	Uphill	*Downhill*	*Uphill*	*Downhill*	*Difference*
Fuel per chain in c.c. .	43·99	40·76	43·36	42·60	
Effect of direction . .	3·23±0·69		0·76±0·70		. .
Mean fuel consumption .	42·38		42·98		0·60±0·49

The table incidentally shows that the mean value of the fuel consumed on the up and the down journey is the same on the two ends, so that if an equal number of up and down measurements have been made the mean value for the fuel consumption is practically independent of the slope. This result held true for the other five comparable experiments done in this field.

The second example, also from Broadbalk, shows the effect of the soil surface on the fuel consumption when ploughing. There was a strip of well-worked fallow between two strips of wheat-stubble. The soil surface was naturally much less compact than on the stubble. The following table gives the fuel consumed per chain by the tractor when ploughing up the stubble and the fallow when fitted with four different types of wheel.

Wheel	*Mean value of drawbar-pull in lb.*	*Fuel consumed in c.c. per chain*		*Difference*
		On fallow	*On stubble*	
A	1,640	45·5	41·1	4·3±0·7
B	1,880	45·7	41·5	4·2±0·6
C	1,700	42·1	38·6	3·5±0·5
D	1,640	45·8	41·5	4·3±1·2

It must be borne in mind that the experimentally measured differences were either smaller than these, or reversed, since the drawbar-pull was higher on the stubble than on the fallow plots. The experiment seems to show that the increase of fuel used on the stubble was not affected appreciably by the type of wheel used.

Occasions can arise, however, when the reproducibility between the runs is poor. For example, during some experiments in which the

efficiency of the tractor fitted with different types of tyre was being examined, the mean drawbar-pull during ploughing began to fall. It was obviously desirable to put up the pull so as to keep the conditions more comparable for the different tyres. But the field had a number of patches of high drawbar-pull which the tractor could only just manage. An attempt was made to keep up the drawbar-pull by continuously adjusting the depth of ploughing, making it shallower on the heavier and deeper on the lighter patches. The adjustment was not very easy to make as the onset of failure of the wheels to grip was very rapid. But the result of the experiment was surprising and definite. There was the same linear relationship between the fuel consumption and the drawbar-pull, but the whole level of fuel consumptions was pushed up by 6 per cent. in one experiment and by 17 per cent. in another.

Optimum length of run.—This is a question of considerable importance, as the amount of useful experimental data that can be obtained from a given area of land will depend on the answer to it. The longer the runs the more accurate would one expect the individual measurements to be, but the smaller will be the number of runs that can be made in a given area. Since the amount of land available for this kind of work is usually limited, it is very important to utilize it with the highest efficiency. Unfortunately this point could not be fully explored when this work was in progress, since owing to special circumstances it was almost irrelevant for the greater part of the investigation being undertaken, so that no extensive data were obtained which would help to answer this question.

Only one direct comparison of three different ploughing lengths, of 2, 3, and 5 chains respectively was made, and that was when the tractor was drawing a three-furrow plough and ploughing up an old pasture field. If any correlation between the fuel consumed and the mean drawbar-pull is ignored, there are no differences between the standard errors over the three distances, but if the correlation is allowed for, the standard error of the 5-chain run becomes lower than those of the other two, because it is only on this run that there is any appreciable correlation. The results were:

Length of run	*Mean D.-B.P. in lb.*	*Mean fuel in c.c./chain*	*Standard error of fuel per run in per cent.*		*No. of runs made*
			Allowing for D.-B.P.	*Ignoring D.-B.P.*	
2 chains . .	1,310	35·1	3·6	3·7	20
3 chains . .	1,380	36·3	3·6	3·8	36
5 chains . .	1,440	35·7	2·7	3·3	24

This apparent effect of the presence of correlation between the drawbar-pull and the fuel consumption for the 5-chain runs and the lack of it for the 3- and 2-chain runs is probably due to the fact that the variations of drawbar-pull within the runs were small, the root mean-square deviation of the drawbar-pull from its mean being between 55 and 60 lb. on mean pulls of 1,300–1,500 lb. Under these conditions the small effect

of the variability of drawbar-pull on fuel consumption can be shown up only on the longer runs. If the variations of the drawbar-pull are larger than this, as they have been on nearly all the other experiments done here, then the correlation between drawbar-pull and fuel consumption can be shown up on runs of 2 and 3 chains. Fig. 1 serves as an illustration of this, as the data on which it is based were obtained on runs of only 2 chains long.

Hence, although no definite conclusions can be drawn from this experiment, it does appear that there is no considerable advantage in having runs longer than 2 to 3 chains. All the other experimental evidence available supports this conclusion, as the percentage standard errors of the fuel consumption per chain for different fields, using lengths of run from 2 to 8 chains, do not seem to depend on the length of run employed.

Two Examples of the Method

(1) *Effect of gear ratio on fuel consumption.*—Two experiments were made to compare the fuel consumption of the tractor per chain when ploughing in first and second gear. The first one was done on arable land that had carried a crop of kale which had failed, whilst the second was done on a pasture.

TABLE 2. *Effect of Tractor Gear Ratio on Fuel Consumed per Chain when Ploughing*

(*a*) *Arable land.* Tyres used 11·25×28 in. Recommended deflections.

Load on land wheel (in cwt.)	12½	14½	16½	
	Fuel consumption in c.c. per chain adjusted to a mean drawbar-pull of 1,960 lb.			
Tractor in first gear	44·3	43·0	46·6	..
Tractor in second gear	40·7	39·8	40·7	Mean
Difference	3·6	3·2	5·9	4·8±0·6

(*b*) *Pasture land.* Tyres used 11·25×28 in. Deflected 50 per cent. less than recommended.

Load on land wheel (in cwt.)	12½	16½	12½—16½	..
	Fuel consumption in c.c. per chain adjusted to a mean drawbar-pull of 1,600 lb.			
Tractor in first gear	43·7	40·4	3·3±1·1	..
Tractor in second gear	35·5	36·3	−0·8±0·8	..
Difference	8·2±1·1	4·1±0·6	..	..

There is clearly a considerable saving in fuel when working in second gear, and this is established quite definitely. There also appears to be a small effect of ballast on the fuel consumption when working in first gear, which is barely significant. The reason it goes different ways in the two experiments is presumably due to the 16½ cwt. load being too heavy for the soft arable and the 12½ cwt. load rather too light for the firm and rather slippery pasture.

(2) *Effect of speed of ploughing on fuel consumption.*—The Case tractor used was fitted with a governor, and experiments were made to see how far the speed of ploughing affected the fuel consumption. The primary reason for doing this experiment is that if one is studying how the fuel consumption of the tractor when ploughing depends upon the type of driving-wheel used, the tractor will normally be ploughing faster the larger the wheel used. Ideally, one should alter the gear ratio in the tractor gear-box in such an experiment so that the forward speed of the tractor is the same for the different wheels. But in the experiments actually made here this could not be done, so that the comparison of different wheels necessitated the tractor working at different speeds.

The speed of ploughing was altered by varying the setting of the governor on the tractor, and in the experiments described here only the so-called full-open and half-open settings were used. Five adequate sets of comparisons were made in all and the results are given in Table 3. The first four comparisons were made on a sandy soil at Woburn, with the tractor working in second gear, and the fifth on a stony clay at Rothamsted with the tractor working in first gear, but in all five the soil was fairly loose before ploughing. In the table the fuel is given in c.c. per chain and the speed in miles per hour.

The mean observed fuel consumptions have been adjusted to allow for the small differences in mean drawbar-pulls for the full- and the half-open governor settings. This is legitimate because the drawbar-pulls are independent of the governor setting, and therefore of the speed of ploughing, as is shown in the second row of the table. The last row of the table shows the loss of precision that would have occurred if the drawbar-pull was not independent of speed, so that the effect of drawbar-pull could not have been allowed for.

These results show quite clearly that variations in the speed of ploughing have no appreciable effect either on the draught of the plough or on the fuel consumption of the tractor per acre. They show clearly the reason why the most economical method is to work the plough at the greatest speed at which it can do passable work.

Accuracy of estimation of the drawbar-pull.—In all the experiments described here the drawbar-pull was estimated by the tractor driver. He usually had an oil pressure-gauge in front of him, and after ploughing or cultivating his measured course he gave his estimate of the drawbar-pull exerted by the tractor during that run. He usually gave his estimate in units of 50 lb., though on a few occasions when the pulls were very even he gave them to 25 lb. This procedure was only possible by smoothing out the very short-period oscillations of the dynamometer needle. The damping adjustment is fairly critical, for if the gauge is damped down too much very misleading readings can be given. In use the damping was adjusted so that the pointer took between 2-3 seconds to reach its maximum value from zero.

In the earlier experiments, as already stated, the dynamometer-dial was attached to the connecting link itself and the tractor driver had to turn round to read it. On several separate occasions, while the tractor was ploughing an 8-chain course, another observer walked beside the

TABLE 3. *Effect of Speed on the Fuel consumed when Ploughing*

	A		*B*		*C*		*D*		*B*
Wheel used	Woburn		Woburn		Woburn		Woburn		Rothamsted
Place of experiment . . .	1,480		1,290		1,430		980		1,770
Mean drawbar-pull in lb. = P	−40±83		53±35		−22±72		−23±41		−23±41
P (full governor) − P (half-governor).	*Fuel* c.c./*chain*	*Speed* m.p.h.	*Fuel* c.c./*chain*	*Speed* m.p.h.	*Fuel* c.c./*chain*	*Speed* m.p.h.	*Fuel* c.c./*chain*	*Speed* m.p.h.	*Fuel* c.c./*chain*	*Speed* m.p.h.
Governor full open	34·29	3·1	30·98	3·4	29·98	3·7	29·46	3·7	41·51	2·5
Governor half open	34·16	2·4	30·73	2·6	29·74	2·8	28·87	2·8	40·98	2·0
Full minus half-governor:										
Corrected for P	0·12±0·70		0·25±0·34		0·24±0·61		0·59±0·29		0·53±0·46	
Not corrected for P . . .	−0·58±1·60		1·03±0·61		−0·01±1·06		0·30±0·65		0·90±0·70	

3988.34

link and entered the dial-reading every 6 to 10 yards. The mean value of these 17–24 readings was taken as the mean drawbar-pull over this run. The tractor driver was found to over-estimate the pull by about 20–25 lb. over a series of 50 comparisons on this basis. In one series his standard deviation over this mean was about 45 lb. and in the second about 30 lb., the difference between the two series being due to the more even pulls in the second set. In the first set the average maximum variation of pull in a row was about 600 lb., and the maximum variation in the mean pull from row to row about 900 lb. In the second set the two figures were 450 lb. and 600 lb. respectively, so the whole range of variabilities was smaller in this set than in the first.

These errors in estimating the drawbar-pull naturally increase somewhat the apparent error of the fuel measurements. But the effect is not very large. In the first set of experiments, when the standard deviation in the estimate of error was 45 lb., the apparent standard error in the fuel consumption per run was about 11·0 c.c. It would have been reduced to 10·0 c.c. if the drawbar-pull had been estimated correctly. In the second set, in one series the standard error of the fuel consumption per run would have been reduced from 11·3 to 11·0 c.c. for one set of determinations and from 15·5 to 14·9 c.c. in another.

It appears therefore that the tractor driver was able to estimate drawbar-pulls over runs of as long as 8 chains with a standard error of between 30 to 50 lb., depending on the variability of the soil, and that this error causes only a negligible increase in the residual errors of the fuel consumption.

Summary

An investigation has been made on how accurately the fuel consumed by a tractor running over distances of 2 to 8 chains (44 to 176 yards) can be measured. It has been shown how the crude measurements can be corrected for certain variable factors, and that when this has been done it is comparatively easy to measure the fuel consumed to about 3–5 per cent. per run.

Examples are given of the kind of results that can be obtained and the precautions that must be taken to ensure that the results are correctly interpreted.

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THE POSSIBILITY OF EXTENDING *CINCHONA* CULTIVATION IN THE BRITISH EMPIRE

SIR GEOFFREY EVANS

Introduction

THE *Cinchona* plant is the base for the manufacture of quinine, which is still the most important specific for malaria, in spite of the advent of synthetic drugs, such as plasmoquene and atabrine. The former drug is not now in favour, as it is said to give rise to certain toxic effects. Atabrine is of German origin and is protected by patents. Its cost is high, and it is stated [1] that the cost of treating one malaria case with it would be 4·9 *s.* as against 1*s.* for a similar treatment with quinine. In view of the fact that vast areas of the territories owing allegiance to the British Crown are subject to this scourge, it is remarkable that about 90 per cent. of the quinine products consumed in the world to-day is produced in the Netherlands East Indies, and that only about 4 per cent. is made in British countries. It has been estimated that there are some 800 million people in the world to-day who suffer from malaria and that there are 2 million fatal cases annually. A large proportion of these casualties are British subjects. For example, the League of Nations Health Organization gives data showing that 100 million people in British India alone suffer from malaria, but only 8 to 10 million are treated annually, and in other tropical parts of the Empire conditions are much the same.

The increased consumption of quinine is largely a matter of price and, running concurrently, of efficient propaganda. With lower prices, a wider knowledge of the nature of the drug and efficient means of distribution, the consumption could undoubtedly be largely extended. Even at present the consumption figures are very considerable. Thus India alone consumes about 210,000 lb. of quinine per annum, of which 70,000 lb. are produced in that country and 140,000 lb. are made from Dutch East Indies bark. The real need for India is provision for 100 million sufferers, using 45 grains a year, which would require 600,000 lb. of quinine sulphate annually. In the Colonial Empire the latest figures, as shown by the imports, indicate a consumption of about 70,000 lb. per annum. Many of the smaller island Colonies, such as Fiji, Tonga, and some of the West Indian islands, do not suffer from malaria and do not, therefore, import quinine. Taking the others, the Eastern Group consumes nearly 47,000 lb., the chief importers being Ceylon (27,500 lb.), Malaya (15,000 lb.), and Mauritius (3,100 lb.). The East African Colonies absorb over 11,000 lb., Kenya, Tanganyika, and Uganda each taking between 2,500 and 3,000 lb. annually. The West African group absorbs only 7,190 lb., an amount which is obviously very much less than the potential demand. In all these Colonies the need for quinine is great, but the obstacle of price, which is greater than the average inhabitant can afford, stands in the way of any immediate increase of consumption.

The whole question of malaria control was specially considered by the Health Organization of the League of Nations. The Special Malaria Sub-Committee of this body inquired into the possibility of utilizing the other alkaloids that are present in *Cinchona* bark in addition to quinine. The conclusion reached was that the stricken peoples of the world would benefit from the use of a cheap febrifuge consisting of mixed alkaloids, provided these conformed to legally defined standards. Totaquina was the result of these deliberations and it is a febrifuge standardized to contain 70 per cent. of crystallizable alkaloids, of which 15 per cent. is quinine. Either it may consist of the total alkaloids of low quinine-yielding species, such as *C. succirubra*, or it may be made from the high-yielding *C. ledgeriana* residues with the addition of sufficient quinine to bring it up to specification. Medical tests, according to Field [2], have proved satisfactory, although it is stated to be slightly less effective than quinine and is unsuitable for intramuscular injections. Here again the question of cost arises, and totaquina is not likely to displace quinine unless it is appreciably cheaper. Theoretically the extraction of total alkaloids from the bark is easier and cheaper than the separation of quinine alone, but prejudice is in favour of quinine, partly because of its more attractive colour and appearance. The price of bark is the real crux of the question, and this is largely controlled at the present time by one organization which holds a practical monopoly, namely, the Kina Bureau of Amsterdam. This controls the production of bark in the Netherlands East Indies, a region which, as has been stated above, provides not less than 90 per cent. of the total world production at present. The supplies from the South American countries, which are the original home of the plant, are now negligible.

Cinchona *and the Early History of its Cultivation*

The genus *Cinchona* is a native of the Andean region and grows in a wild state on the eastern afforested areas of that region, between latitudes 10° N. and 9° S., in the Republics of Peru and Bolivia. There are 65 species of the genus *Cinchona* listed in *Index Kewensis* and all are characterized by possessing bark containing the quinine alkaloids to a greater or less degree. The classification has presented some difficulty to botanists, owing to the ease with which the species hybridize with one another, so giving rise to different forms. There are, however, only four species which are, or have been, cultivated to any extent for their alkaloids. These are *C. ledgeriana* Moens ex Trimen, which is also known as *C. calisaya* Wedd. var. *ledgeriana* Howard, from which Ledger Bark is obtained; *C. succirubra* Pavon ex Klotzech, which produces Red Bark; *C. calisaya* Wedd., yielding Yellow Bark; and *C. officinalis* Linn., giving Crown Bark or Loxa. There are two hybrids which have been cultivated from time to time, namely, Ledger Hybrid (*ledgeriana* × *succirubra*) and *C.* (*robusta* × *officinalis* × *succirubra*). Nowadays practically all the Cinchona bark of commerce is obtained from *C. ledgeriana* and *C. succirubra*. In Java selected plants of *ledgeriana* have given higher percentages, and in fact the contents of quinine and alkaloids seem to vary somewhat according to variety and also to environment.

Cowan [3] gives the following average percentages of the three main species as grown in India:

	Quinine	*Other alkaloids*	*Total alkaloids*
C. ledgeriana . . .	5·49	3·03	8·52
C. officinalis . . .	2·93	2·07	5·00
C. succirubra . . .	1·40	4·85	6·25

Analyses of the bark indicate that *C. ledgeriana* is richer in quinine than any other species, but that *C. succirubra* possesses a high total content of alkaloids, particularly in cinchonidine. These facts are of great importance in connexion with the establishment of the planting industry, as naturally efforts have been made to cultivate *ledgeriana* on account of its high quinine-content, in spite of the fact that it is more particular in its requirements and is less easy to grow than the other species.

The history of the introduction of the plant to cultivation throws considerable light on the present state of the industry. Prior to 1857 supplies of bark were obtained in limited quantity from the native home of the tree in Bolivia and Peru, hence its old name of Peruvian Bark. It had long been known as a fever-freeing drug, as in 1639 the Countess of Chinchon, wife of the Spanish Viceroy of Peru, was cured by a decoction of the bark. A hundred years later Linnaeus perpetuated the name of this lady by giving the genus the name *Cinchona*.

No real effort seems to have been made to cultivate the tree in the South American forests, or to maintain supplies by replanting, and as the demand for the drug increased, especially after 1820, when French chemists isolated the main alkaloid from the bark and quinine sulphate became the established specific, the importance of securing more abundant and regular supplies became evident. Between 1845 and 1848 Dr. H. A. Weddell investigated the natural occurrence of Cinchona trees in South America and described the species. He commented on the reckless clearing of the forests and pointed out that cultivation would have to be undertaken if supplies were to be maintained. Weddell's seed was planted in the Jardin des Plantes at Paris, and a few years later, one of these plants was taken to Java, supplemented later by importations of seed and plants from South America and by exchange from India. Stimulated by his report the East India Company decided to dispatch an expedition to South America to obtain seeds and, if possible, plants, and placed Mr. (later Sir) Clements Markham in charge. A brief account of his journey is given by Dr. George Smith [4]. Markham succeeded in collecting 529 plants, together with a quantity of seed, chiefly of the *calisaya* variety from 'the Province of Caravaya' in Peru. He arrived at Southampton in 1860, and after transmitting a portion that were dying to Kew [5], he proceeded with the remainder to the Nilgiri Mountains in Madras Presidency, and eventually 270 survived the passage of the Red Sea. Meanwhile seed had been dispatched to Kew where, under Treasury instructions, a forcing house had been erected. A large number of seedlings were raised there in 1860–1, young

stocks grown, and competent gardeners recommended to take charge of the new plantations in India. At the same time seed was supplied to the West Indies and Ceylon. The plants thus collected appear to have been chiefly of the two species *succirubra* and *officinalis*, neither of which possesses a high quinine-content. The next step was the introduction into cultivation of *C. ledgeriana* in 1865. Charles Ledger was an explorer and merchant, and an interesting account by Holland [6] relates how his henchman managed to collect seed from fifty trees of the 'rojo' sort from the banks of the Mamore river in Bolivia. Ledger sent the seed to London, where it arrived in good condition, and asked his brother to sell it to the British Government. He was unable to do this and sold the greater part of the seed (about 13 lb.) to Mr. J. W. B. Money, who owned cinchona plantations in India. The latter did not use the seed himself, but exchanged it for *C. succirubra* seed with McIvor, the head of the Government Cinchona Plantations in Madras, since this variety appeared to be well suited to Nilgiri conditions. Little care seems to have been taken with Ledger's seeds in Madras, and although about 60,000 seedlings were said to have been raised, they were allowed to die out because the policy at that time was to concentrate on *succirubra*. A small pinch of seed had meanwhile been obtained by G. A. Gammie, the Superintendent of Cinchona Plantations in Bengal, and 800 seedlings were raised. Partly because the species appeared to do better in the Himalaya foothills than in the Nilgiris, and partly also because the true value of the *Ledgeriana* species was better appreciated, it was multiplied rapidly and soon began to replace the inferior varieties in the Bengal plantations. Meanwhile Ledger had disposed of his remaining seed amounting to 1 lb. to the Dutch Government, who sent it to Java, where it came into the possession of the Director of Cinchona Cultivation, J. C. Moens, in 1865. The new species took kindly to the soil and climate of Cheribon and Preangar, where most of the *Cinchona* is still grown to this day. The value of the new introduction with its high quinine-content was at once realized, and the Dutch with their usual thoroughness immediately began a system of rational selection which has borne abundant results.

According to Kerbosch [7], the planters in Java early formed the opinion that the large-scale production of *Cinchona* bark with a low quinine-content would have no economic future. Accordingly, when *Cinchona* plants were first introduced by Markham, Hasskarl, and Schuhkraft, the planters took little interest, since these species, mainly *officinalis* and *succirubra*, produced bark with a low quinine-content. There was a change in the situation in 1873, by which time the first consignment of bark with a high quinine-content was produced from the plants raised from the seed purchased from Ledger in 1865. Private enterprise then began to develop plantations on a large scale, more especially as the medical profession was advocating more and more strongly the use of the drug, with the result that the market strengthened and widened. Ceylon was at that time a keen competitor of Java, as the planters had been anxious to find a substitute for coffee, which was being destroyed by the fungus disease *Hemeleia vastatrix*, and had

substituted *Cinchona* for it. The area planted to *Cinchona* in Ceylon jumped from 1,500 acres in 1873 to 64,000 acres in 1883, but by then over-production had taken place and the price of bark fell from 72 Dutch cents in 1880 to 7½ cents ten years later. The Ceylon bark with the low quinine-content was at a serious disadvantage with the Ledger bark produced in the Dutch East Indies, and the industry declined rapidly. The area in 1893 was only 5,000 acres, and the *Cinchona* trees were grubbed up to be replaced by the new plantation crop—tea—which was then coming into favour and was found to grow well under the same conditions as *Cinchona*. To-day the Ceylon industry is dead.

In India the position was in some ways similar to that in Ceylon, with the difference that Government-owned plantations were maintained in the Nilgiri Hills of Madras and in the north-east of Bengal on the Sikhim border. These two regions are still the centres for quinine production in India, but private enterprise has ceased and only the Government plantations remain. At the height of the boom in 1880 it was estimated that the Government and private plantations in the Nilgiris and other parts of southern India amounted to 5,800 acres, with a production of 400,000 lb. of dry bark per annum. The Government plantations at Munsong and Mungpoo in Bengal covered 2,400 acres and private plantations in Darjeeling another 1,800 acres, the former producing 400,000 and the latter 150,000 lb. of bark per annum. In Ceylon at the same time the corresponding figures were 33,500 acres and 1,000,000 lb. of bark, Java at that time possessing 7,500 acres and 450,000 lb. In all parts of India the slump in prices caused by over-production saw the elimination of private plantations during the next decade.

There were essential differences in the management of the Government plantations in Madras and Bengal. In Madras, the policy had been to grow *succirubra* and to a less extent *officinalis* and *robusta*—species possessing a much lower quinine-content than *ledgeriana*. The reasons for this policy were partly that these species were those first introduced at the time of Markham's successful expedition, and also because conditions of soil and climate seemed to suit them better than *ledgeriana*. In Bengal, on the other hand, the value of *ledgeriana*, on account of the high quinine-content of its bark, was realized from the time when the first small consignment of seed had been secured with so much difficulty, and efforts were largely concentrated on the problem of establishing this species, so that up to the present time by far the greater part of the area is still planted in *ledgeriana*.

Cinchona was also tried in the early days in many parts of the British Empire, and apart from Ceylon and India, experiments were carried out in Malaya, the Sudan, St. Helena, Jamaica, Trinidad, Mauritius, and parts of Australia and New Zealand. In most of these places climatic conditions proved to be unsuitable, but in Jamaica a small industry flourished during the boom period. The area cultivated in 1880 was estimated at 800 acres and the production at 50,000 lb. of bark per annum, but the economic conditions that proved so fatal in Ceylon and India also applied to Jamaica, and the industry speedily declined, so that at the present time all that remains to perpetuate the attempt is the

name 'Cinchona' which is given to a pleasant old house situated high up in the Blue Mountains and the head-quarters of an old experimental garden of the Department of Agriculture.

This record of failures in the British possessions is in marked contrast to the state of the industry in the Dutch East Indies where it continues to flourish to-day. It will be interesting to examine the reasons for this success and the methods by which difficulties have been met and overcome.

Causes of Success of the Dutch Industry

Kerbosch [7] mentions that the effect of the slump in prices during the 'eighties caused by over-production was felt for twenty years afterwards, and the price reached such a low level that many undertakings in Java could hardly work at a profit. In fact, there was a danger during this period that *Cinchona* cultivation might be abandoned in favour of another crop, as happened in Ceylon. The first real improvement came in 1913 when the producers in the East Indies came to an agreement with the manufacturers of quinine whereby the supply and sale of bark was regulated to keep pace with the world's consumption. This arrangement probably saved the estates from financial ruin, but has not really prevented the possibility of over-production, for far more bark could be obtained by the normal working of the estates than is now allowed to be produced by the agreement. A rapid expansion in output could, therefore, become effective, if the position of the market warranted such action.

Mention has been made of the measure of co-operation maintained between the growers and the quinine manufacturers which was achieved through the Cinchona Agreement of 1913. The administration of the Cinchona Agreement lies with the Kina Bureau in Amsterdam, which is made up of representatives of both growers and quinine manufacturers. Government influence is of importance, as about 10 per cent. of the production of bark comes from Government-controlled plantations. Since 1934 bark production has been further controlled by the introduction of an export quota system, and Government decrees the amount of bark that shall be exported annually. Thus, in 1936 the export quota was fixed at 1,646,851 lb. (expressed as quinine sulphate equivalent), but in order to meet the world's heavy demand the quota was increased in November by another 157,630 lb. The figures for 1937, 1938, and 1939 have been progressively lower. The producers of bark have benefited greatly by this restriction scheme, which was extended for another ten years on January 1, 1937. The feasibility of this agreement was only possible because the Netherlands East Indies possessed by 1913 a virtual monopoly of production. At least 90 per cent. of the world's supply was in their hands, owing to the collapse of private enterprise in Ceylon, South India, and other places. It must not be imagined, however, that this position has been easily reached, as prior to 1913 the industry had many bad periods.

Some of the reasons for the survival of the Java industry when its competitors failed may be briefly mentioned. In the first place, the

climate of those parts of Java where *Cinchona* is grown appears to be particularly favourable to its growth, and especially to *ledgeriana*. The light volcanic soils also seem to be very suitable. But apart from this, due credit must be given to the way in which the early Dutch adopted the policy of concentrating on varieties producing bark with a high quinine-content. The industry has also been the subject of unremitting research by the Government Cinchona Plantation at Tjinjeroean, and rigorous control in the selection and breeding of new high-yielding varieties has given planting material of the highest quality. At the same time, field experimental work has been undertaken with the object of overcoming the difficulty of growing *ledgeriana* in old soils and in the introduction of grafting technique and the selection of root-stocks. Work to combat soil losses from erosion by terracing, drainage, and the use of green manures, has been continued, and manurial experiments carried out. These factors, in addition to the economic agreement, have served to place the industry in its present satisfactory position.

C. ledgeriana requires rather special ecological conditions in order to flourish. As regards climate, it will not stand great heat, and frost is fatal. The ideal mean temperature is probably about 75° F. with a mean minimum of 60° F. and mean maximum of 85° F. The limits of rainfall fall between 75 and 150 in. per annum, but the distribution is far more important than the total precipitation. The plant cannot stand long periods of drought and it is therefore found in the East that it is cultivated only in those districts experiencing two monsoons in the year. 'Ledger' also is particular in its soil requirements. Sands [8] mentions that in Java it grows on light loams of volcanic origin of good depth, rich in plant-food, and easily worked. Clay soils are said to be quite unsuited and free drainage is essential. In India it is also found that soils derived from granitic and volcanic formations are the best. They are acid and have a fairly wide range from a pH of 5·23 to 4·58. As regards elevation, *Cinchona* is grown in Java between 3,500 and 6,000 ft. above sea-level. Below or above these levels the yield is not good. In India the upper limit is 5,000 ft. and the lower about 1,500 ft. At low levels the tree grows rapidly, but has a short life, is liable to disease, and the bark has a low percentage of alkaloid. At the higher levels the growth is slower and the yield of bark is smaller. *C. succirubra* is somewhat less exacting in its requirements both as regards elevation, soil, and rainfall, but the same general conditions apply to it as to *ledgeriana*. It will thus be seen that the plant is exacting in its requirements, and it is natural, therefore, that the number of localities suitable, and the areas of land available, are somewhat limited.

Cultivation

In India the sequence of operations is as follows. A suitable area of virgin rain-forest is selected and felled during the cold season (November to March). If steep, this land is terraced and staked 4 × 4 ft. to mark the sites of the young trees, which are planted out from the nursery beds in specially prepared holes, during May, and continuing for the next two months when rainy conditions prevail. In Darjeeling light shade-trees only

are needed, but heavier shade is required in Madras and Burma. Seedlings are raised and used as plants, and although experiments with grafting have been made, the practice of planting out seedlings still prevails in India. The soil of the nursery-beds is carefully prepared from leaf-mould collected from the forest. It needs to be worked to a fine consistency, since the seed is very small and light and one ounce will give 20,000 seedlings. It germinates in about three weeks. The nursery-beds are sheltered by sloping roofs of thatch to protect the young seedlings from heavy rain or sun, and seeds are sown in March. They must be carefully watered with a fine spray at regular intervals. The seedlings are transplanted twice, first when the seed-leaves are just fully expanded to a distance of 1 in. apart, and later at the age of three months, in May and June, when they are 2 or 3 in. high, and then the spacing is 3×3 in. They are planted out after they have been in the nursery for about two years, and a fortnight before they are transplanted, the roofing of thatch is gradually removed to harden off the plant. The young plantation is cleared about twice a year for the first two or three years, but later periodical hoeing round the tree is all that is required. Harvesting of the bark begins about the fourth year when thinnings and prunings are dealt with. The final uprooting is made in the 10th year, as the figures available indicate that a ten-year rotation gives the greatest return in quinine per unit of area. At the final harvest, the whole tree is uprooted and the bark stripped from roots, stems, and branches, which is then dried, stored, and passed to the factory. This method is said to give better results than a system of coppicing, which has also been practised.

The system employed in Java differs essentially, as grafted plants are utilized as well as seedlings. The methods employed for raising seedlings are essentially similar to those described above, except that the seed-beds are more elaborate and the times of transplanting somewhat different. The *ledgeriana* plants are all raised from specially selected trees. These are chosen for their strong, healthy growth, erect stem and erect branching habit, size and colour of leaves, thickness of bark, quinine-content, age at which first flowers are formed, and resistance to disease. The age at which the tree flowers is important, as early flowering is correlated with loss of vegetation vigour. Strains with reddish leaves of medium size are favoured by planters, and trees with an erect branching habit are not so apt to crowd each other as types with a spreading habit. The original trees raised from seed purchased from Ledger, many of which are still living at the age of 60 years, showed considerable variability, particularly in the quinine-content, which is stated to range from 3 to 13 per cent. The care which has been exercised over so many years in selecting material with a high quinine-content for planting, is one of the reasons why the industry has been able to weather so many vicissitudes in the past and is now in its present profitable state.

C. succirubra is grown on a few small estates where the elevation and soil are not so suitable for *ledgeriana*, since it is hardier, more adaptable and possesses a stronger root-system. It is for these reasons grown on all the large estates, not for its bark, but as a root-stock for grafting purposes. Sands gives an interesting account of the method of grafting, and

states that the percentage of grafts which grow is usually over 90. The grafted plants are ready for the field in 8 or 12 months after grafting. From the time of planting the *succirubra* seed to the planting of the grafted plant in the field, a period of about three years is necessary. *Ledgeriana* seedlings are usually planted on newly cleared forest land, but it is said to be hard to establish on old land, and as the area of virgin forest that remains is now limited, resort has been had to grafting selected *ledgeriana* material on to *succirubra*.

Progress has also been made in the Belgian Congo in recent years. Stoffels [9] gives a good account of the methods employed in raising seedlings and in grafting *ledgeriana* scions on to *succirubra* stocks, which differ in certain details from those used in Java. It is obvious from this brief account that research has played a vital part in the Java industry from the early days. In a recent report to the Imperial Council of Agricultural Research for India, the need for systematic research on similar lines in India is stressed. In the early days outstanding work was done by McIvor in southern India and Gammie in Bengal, and much of the *Cinchona* was propagated by vegetative methods on the Government Cinchona Plantations, but in recent years research has played a subordinate part and the small and inadequate staff has had to concentrate on the work of supplying bark, extracting the alkaloid, and dispatching the produce of the factories. The policy has been so to work the Departments that they entailed no loss to the State. The Java Reports for 1938 show that the *Cinchona* bark produced in that country worked out at 8 per cent. of quinine sulphate, whereas the corresponding figure for India was about 4 per cent. It is recognized that the soil conditions and rainfall distribution are not so favourable in India [10] as they are in Java, but it is believed that a properly organized research station ought to be able to raise the percentage to 7 within a reasonable time. Attempts to graft *ledgeriana* on to *succirubra* stocks in India have met with indifferent success up to the present, but it is suggested that three-quarters of the failure is due to ignorance of the correct technique. In Java, trained artisans can make over 200 grafts a day with an astonishing degree of success, and there seems little doubt that with perseverance and due encouragement, similar results ought to be obtainable in India.

Possibilities of Extension in the British Empire

Too complete a reliance on one country for supplies of this vital product, which might prove dangerous in times of war, have recently caused another enquiry to be held into the possiblity of extending the cultivation of *Cinchona* within the borders of the Empire. This has shown that the areas with the exacting conditions of climate and soil suited to its growth are definitely limited, but it will be of value to record the progress that has been made in recent years to establish or extend new plantings.

India and Burma.—In India the present position is that the possibility of extension in Bengal is very limited, whilst in Madras new areas are being tried out in the Anaimalais, and a recent report by Wilson and Mirchandani [11] indicated that enough first-class land existed for an

early resumption of *Cinchona*-growing, about 38,000 acres of first-class land being available in Bengal, Assam, Orissa, Bhutan, Sikhim, Madras, Mysore, and Coorg. The production of *Cinchona* by planters has now practically ceased. The old plantings in the Darjeeling district have long ago been replaced by tea and those in southern India have been grubbed up and abandoned or replaced by coffee or some other crop. Further recent attempts to interest the planting community in this crop have not proved successful. A manifesto addressed to the Government of Madras by the Planters' Association, as lately as August 1938, laid down the following conditions as essential to any such project:

1. A guarantee to absorb the production from *Cinchona* estates, provided the bark is of good quality.
2. A guarantee to pay the market rate subject to a fixed minimum.
3. Partial remission of land assessment on areas planted in *Cinchona* for a certain period.
4. The planters to guarantee not to sell their bark to anybody except the Government.
5. Government to have the right to limit the areas to be planted.

The matter of a guaranteed minimum price had been the subject of repeated representations from 1895 onwards, and finally in 1925 the Government refused. Accordingly, after an agreement with the Planters' Association, new lands in the Anaimalai Hills were opened up by Government in 1925 in order to supplement the supply of bark from the Nilgiri plantations. These new plantations appear to be doing well and unlike other areas in south India, the *ledgeriana* species seems to be doing better. There the matter rests at present.

Practically all the quinine now produced in India is grown and manufactured by Government, but this is only sufficient to meet one-third of the annual consumption, the rest being purchased from Java. It seems improbable that private enterprise will undertake *Cinchona*-planting unless a guaranteed minimum price is forthcoming, and the alternative to continued dependence on Java is for the Goverment to expand its own plantations.

Attempts to establish *Cinchona* plantations in Burma were made following the report of Lt.-Col. A. T. Gage [12], who was commissioned to inquire into the possibility of increasing *Cinchona*-planting in the Indian Empire, under instruction from the Government of India. In this report the suggestion was made that the hill ranges of Tavoy could probably furnish all the quinine needed by the British Empire, and also that the proposed plantations should come under the direct control of the State. Work in establishing the new plantations was started in 1920, but those in Tavoy were destroyed by heavy rains in 1921 and 1922. Accordingly, a new site was chosen in Mergui district in 1923. This also was not a success, because of the low elevation and the abnormally long dry season. Difficulty was also experienced with labour. This plantation was closed down in April 1937, when under the new constitution Burma became separated from India, and she refused to assume the financial responsibilities involved. There are many who remain convinced that there are considerable possibilities for *Cinchona* in Tavoy, particularly

in the ranges farther inland from the coast where the rainfall is not so torrential.

East Africa.—It has already been shown that trials of *Cinchona* were made in earlier years at a number of places where it was considered that conditions offered a reasonable chance of success. Many of these experiments failed, but in one or two colonies, such as Ceylon and Jamaica, better results were obtained and a considerable industry was built up, only to collapse during the period of over-production in the eighties. In the post-war period the unsatisfactory position of Empire-grown supplies was considered by the Imperial Government. In 1925 the Committee of Civil Research appointed a sub-committee to inquire into Empire supplies and reported that any scheme for extension would be premature, pending further information about synthetic products, but that in any event it would probably be necessary to create new plantations if the Empire was to be self-supporting in quinine and *Cinchona* alkaloids. As a first step, a grant of £2,000 a year was made to Amani in Tanganiyka to enable that research station to carry out experimental work and restore the old plantations. It must be remembered that the Germans had imported seed of *ledgeriana*, *succirubra*, and the hybrid from Java, as early as 1901 and had established plantations and a factory at Amani for the production of quinine. These plantations were all cut down during the East African campaign, and the quinine so produced was an important factor in preserving the health of their forces. The old plantations had coppiced or ratooned freely, and the grant was utilized not only to regenerate the old German plantation, but also to plant new areas. Following a progress report in 1930, a sub-committee of the Colonial Advisory Council of Agriculture was appointed in 1931, and it advised against any further work, mainly on the grounds that the use of quinine as a specific for malaria was likely to be displaced by more efficient synthetic products. As a result, all the *Cinchona* trees at Amani were cut down and the bark stripped, except a plot of *C. ledgeriana* which was kept for seed. An interesting account of *Cinchona* in Amani at the present time is given by Worsley [13], together with analyses of the different kinds of bark and costs of production. It is noted that at Amani, as elsewhere, *ledgeriana* produces less bark than *succirubra*, but gives higher quinine percentages, which were on the whole satisfactory. In 1936, following representations made by certain Colonial Governments, the quinine position was again reviewed by the Colonial Agricultural Advisory Council, and as a result *Cinchona* research is now included in the programme of the Amani Institute. The most recent reports show that in addition to the plantations controlled by the Institute, there are about a dozen privately owned plantations in the Usambara Mountains, which have areas of old plantings as well as young trees. Research at Amani indicates that the soils are patchy and that the best areas are situated in the wetter parts of the western Usambara Range, where the rainfall is heavier and better distributed. Young *ledgeriana*, when grown in suitable situations and on the right type of soil, is showing considerable promise. The work so far carried out indicates that there is much to be learnt, since the methods of cultivation employed in India or Java cannot

be adopted wholesale in this part of Africa. As an instance, trees growing under shade are promising, whereas this practice is not the rule in India. Further, the old *Cinchona* trees at Amani have regenerated surprisingly well from coppicing, which is not the case in other *Cinchona*-growing countries, where the trees after they have reached the age of eight years or so are grubbed up, barked, and replanted with young trees. Whether coppicing will prove the best practice in the long run remains to be seen. Investigations are also being conducted into the control of the *Armillaria* root disease, which, together with *Helopeltis*, causes some loss. In the meantime, the Amani nurseries are supplying seedlings to the private planters in the area. The varieties issued consist chiefly of *ledgeriana* and its hybrid, together with *succirubra*, which seems to grow particularly well and possesses a fair quinine-content. The question of establishing a factory depends on whether the consumption of quinine in East Africa would justify the cost.

West Africa.—Experiments are being conducted in the Mandated Territory of the Cameroons. As in Tanganyika, *Cinchona* was first introduced by the Germans about thirty years ago, and three small plantations were established, two being near Buea at altitudes of 3,200 and 3,500 ft., and another higher up the mountain at Musaka (5,600 ft.). Many trees were cut down during and after the war and no further interest was taken until 1923, when these areas were surveyed, new seedlings planted, and 1,047 trees counted. By 1927 the number of living trees had been reduced to 521. The old trees were found to have coppiced quite well in some places, and the proportion of trees still alive was considered satisfactory in view of the years of neglect that had elapsed. The soils are of volcanic origin and the rainfall conditions appear to be favourable. Recent work has led to the conclusion that *succirubra* is more suited to conditions than *ledgeriana*, which is giving disappointing results when grown on its own roots. As it was thought that the only hope of establishing an industry was to produce ledger bark, selection work on this species was commenced in 1937, and 23 of the most promising trees were selected for vegetative propagation. Care is being taken to preserve these trees by manuring, as some of them are in a bad way, owing to long years of neglect. Meanwhile investigations to inquire into the possibility of budding or grafting on to *succirubra* stocks were started in 1939. Budding was found to be impracticable, but grafting was more successful. It has been found that by using young, vigorously growing twigs, which were only slightly woody and had a soft, pliable, light-coloured bark, a fair percentage of successful grafts could be made. By the end of 1939, 1,140 grafts had been made and 43 per cent. were successful, dealing with 12 clones. More success was obtained with some clones than others, but this is probably due to the actual condition of the parent tree. In the meantime, the supply of *succirubra* stocks is being increased, and it should be possible by the end of 1940 to supply small quantities of grafted plants for experimental planting on estates. Further progress will depend on the manner in which these plants flourish and on the price of bark and other economic factors.

Malaya.—Much work has been done in recent years at the Agri-

cultural Station in the Cameron Highlands. Here excellent growth has been made by both *C. succirubra* and the hybrid seedlings, but seedlings of *C. ledgeriana* are slow in growth and lack vigour. On the older areas this species was also in an unhealthy condition, being attacked at the base of the stem by the weak parasite *Phytophthora cinnamoni*, which is associated with weak, unhealthy trees. Experiments made here also seem to indicate that *ledgeriana* growing on its own roots is not likely to be successful, and steps are now being taken to graft it on to *succirubra* seedlings, which grow much better under local conditions.

New Guinea.—Trials with four kinds of *Cinchona* have been made at the newly established Agricultural Station at Aiyura, which is situated at about 6,000 ft. on the divide between the head-waters of the Ramu and Markham rivers. Although these trials are still in their early stage, growth is satisfactory and soil and climate are said to be suitable for *ledgeriana* [14].

Ceylon.—Interest has again revived in *Cinchona*, and a recent report by Haigh [15] expresses the opinion that Ceylon has a reasonable chance of producing quinine more cheaply than she can buy it. Preliminary trials have been made and seed-beds planted at Malpota. A survey of suitable areas between 3,000 and 5,000 ft. has been made, and it is proposed to plant one-acre test plots on nine representative areas as a preliminary step. Budding and grafting trials are also being carried out with the object of determining the most suitable technique.

Summary

In conclusion it is important to remember the factors that are necessary to establish a *Cinchona* industry. They are not only concerned with the successful production of bark. As indicated in this note, there is probably sufficient suitable area in the Empire to provide all the quinine it requires. It has been estimated that India alone possesses 38,000 acres of first-class land for this purpose, and there are other large potential areas scattered throughout the Empire, in many of which experiments are now being conducted with promising results. The costs of production have proved difficult to estimate, but in Bengal it may be assumed to be around Rs. 10 per lb. (the rupee = 1*s.* 6*d.*). But the experience of the Cinchona Departments of India indicates that the difficulty was chiefly that of distribution. Production is one thing—consumption is another. Given the necessary financial backing and an organized official drive against malaria, much could be accomplished. Lacking these preliminaries, success for a planting industry would appear to be problematical. It must be remembered that the Kina Bureau controls the quinine market, and, as has already been pointed out, it is regulating production from the Java plantations, which can readily expand their output to a very considerable extent, should the necessity arise.

The desire to render the Empire less dependent on outside sources for supplies of this essential specific is natural, but if production is to be increased, it will either have to be done by the establishment of *Cinchona* plantations and factories by the Government, as in India, or by private enterprise. If the latter is to be encouraged, the need will arise to con-

sider State assistance in the shape of a guaranteed minimum price for bark over a period of years, to be accompanied by an organized drive to popularize the use of quinine, and the establishment of an adequate system of distribution.

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FORM AND DATE OF NITROGENOUS MANURING OF COTTON IN THE SUDAN GEZIRA

FRANK CROWTHER

(*Plant Physiologist, Agricultural Research Institute, Anglo-Egyptian Sudan*)

MANURING experiments (1, 2, 3, 4), made at Gezira Research Farm and elsewhere in the Sudan Gezira Irrigation Scheme in the decade 1924–34, had shown that considerable increases in yield were obtained from nitrogenous fertilizers applied to the cotton crop. The conclusions from these experiments, in most of which ammonium sulphate was used, may be summarized as follows:

1. Seasonal variation in the response per unit of nitrogen was great, but generally maximum yields were obtained with the heaviest application (usually 600 lb. ammonium sulphate per acre).
2. The optimum date of fertilizer application appeared to be about six weeks after sowing, but in some years applications about sowing-time were equally effective.
3. Early-sown cotton gave larger increases than late-sown.
4. A closely-spaced crop responded more to the fertilizer than one more widely spaced.
5. A heavily-irrigated crop gave greater increases than one lightly irrigated.

The experiment[1] here described examined two problems, the most suitable type of fertilizer and the optimum date of application, studied in relation both to one another and to the most effective amounts to apply. It was repeated during five successive seasons to determine the extent of seasonal variation and to obtain a reliable average.

Gezira Research Farm, the site of the experiment, is at Wad Medani (Latitude N. 14° 24″, Longitude, E. 33° 31″). The normal annual rainfall is about 16 in., most of which falls in July and August. The cotton is of Egyptian type (*Gossypium barbadense*), and is irrigated by canal-water from the Blue Nile dam at Sennar. It is sown in mid-August, during the cool weather of the rainy season, and harvest lasts from January until April. The cotton crop of the experiment was one phase of a three-year rotation: (1) cotton, (2) *Sorghum vulgare* followed by *Dolichos lablab*, and (3) fallow. The Gezira soil is a 'heavy clay, strongly alkaline, of low permeability to water, and low in content of nitrogen and humus' [5].[2]

The obvious fertilizer to compare with ammonium sulphate was one containing nitrate, so that the relative merits of ammonia and nitrate,

[1] The experiment was designed by E. M. Crowther, of Rothamsted, and M. A. Bailey, late Director of Agricultural Research in the Sudan, and the field work was under the direction of, first, E. Mackinnon and, later, E. R. John, Inspectors of the Department of Agriculture and Forests.

[2] For further details see L. Bluen [6] and F. G. Gregory *et alia* [3].

as sources of nitrogen supply, could be compared directly. Sodium nitrate was banned theoretically on the ground of the high sodium-content of the soil, and therefore calcium nitrate was selected.

The factors compared were as follows:

Type	*Date of application*	*Amount of nitrogen*
1. Calcium nitrate	1. 7½ weeks before sowing	0N Nil
	2. 2½ weeks before sowing	1N 40 r.p.f.[1] (38·2 lb. per acre)
2. Ammonium sulphate	3. 2½ weeks after sowing	2N 80 r.p.f. (76·4 lb. per acre)
	4. 7½ weeks after sowing	3N 120 r.p.f. (114·6 lb. per acre)

Applications in June, several weeks before sowing, were included to extend the range of dates examined. This extension was suggested by the results of former experiments, which, despite the torrential rainstorms that fall regularly in July and August, had shown large increases with applications just before sowing.

The variety changed during the five seasons with the introduction of improved strains by the Plant Breeding Section [7, 8] of this Institute. The first year had X 1530, the second and third years X 1530 A, and the last two years X 1730 A. The new strains yielded up to 30 per cent. more than the original Sakel [7]. These changes in variety, while providing a comparison with commercial areas growing the same type of cotton, render impossible a detailed examination of seasonal variation in manurial response.

The dates of sowing in successive years were August 19, 20, 15, 14, and 14. The fertilizer applications were rarely more than 2 or 3 days removed from the theoretical dates.

The gross area of the experiment was 5 feddans. To avoid confusion of direct and residual effects a new site was found each year and the layout was randomized afresh. Thanks are due to F. Yates of Rothamsted for indicating the method of layout and for undertaking the early statistical analyses. The 32 treatments (including dummies), 4 Amounts × 4 Dates × 2 Types, were duplicated, making 64 plots in all, each with an area of 1/22 feddans. Instead of two 32-plot blocks, four 16-plot blocks were adopted, by confounding one degree of freedom from the second-order interaction. The form of the analysis of variance was as shown on p. 127. The further partition of the three degrees of freedom for amounts of nitrogen under 'type totals' tests the curvature of the yield increases with increasing rates. When differences between the two types are examined the further partition of the three degrees of freedom for amounts of nitrogen shows whether or not the two fertilizers differ consistently at different rates of application.

For some reason not at present understood the land of the Farm allotted to this experiment gave consistently higher mean yields than those obtained on the Gezira Research Farm and in the Gezira Scheme.

[1] r.p.f. = rotls per feddan; 1 rotl = 0·99 lb.; 1 kantar = 315 rotls; 1 feddan = 1·038 acres; 1 kantar per feddan (k.p.f.) = 300·6 lb. per acre.

The yields of the unmanured plots and the corresponding commercial yields are listed in Table 1, together with the standard errors of the experiment.

			Degrees of freedom
Blocks			3
Treatments:			
(*a*) *Type totals*			
Amounts of N	3		
Dates of N	3		12
Amounts × Dates	6		
(*b*) *Type differences*			
Amounts of N	3		
Remainder, including (partially confounded D.F.)	9		12
Error:			
Dummies	6		
Remainder	30		36
		Total	63

The standard error per plot approximated to 7 per cent. over the five years, which compares favourably with experience of randomized blocks in other countries.

TABLE 1. *Mean Yield and Standard Error of Experiment*

Year	*Experiment yield* (0N *plots*)	*Gezira Scheme mean yield*	*Standard error of experiment*	
	k.p.f.	k.p.f.	k.p.f.	Per cent.
1935–6	5·28	3·72	0·518	7·2
1936–7	5·87	4·46	0·500	6·1
1937–8	6·38	4·54	0·518	7·1
1938–9	7·03	4·42	0·784	8·8
1939–40	4·93	3·90	0·299	4·8

Results of the Experiment

The mean response to nitrogen was considerable, and similar in extent in four of the five years, as is shown in Fig. 1*a*. For reasons at present undetected, responses were small in the 1937–8 season. Each season's curve shows the familiar falling off in response per unit of nitrogen with higher rates of applications. In all years maximum yields followed the heaviest dressings, suggesting that still greater yields would have been obtained with rates exceeding 115 lb. nitrogen per acre. This is surprising in view of the abnormally high yield of the unmanured land.

Type of nitrogen.—Throughout the experiment calcium nitrate yielded more than ammonium sulphate per unit of nitrogen, as is shown in Table 2.

All years showed the superiority of nitrate, and the differences reached a significant level in four of the five years. In one year the superiority exceeded 40 per cent. and in two other years 30 per cent. Thus the degree of superiority fluctuated from season to season.

Fig. 2*a* shows the increases per additional 40 rotls nitrogen in the two forms for the average of the five seasons. Whereas at *the lowest rate* (1N) *the nitrate fertilizer gave a 50 per cent. greater increase than the*

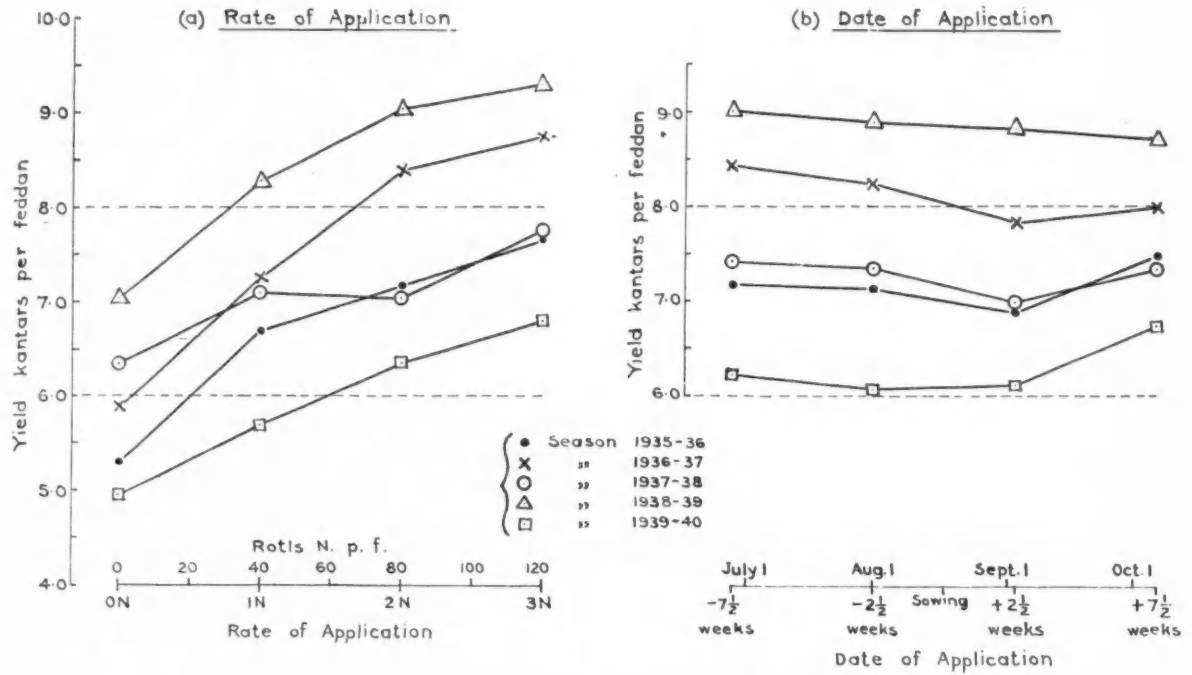

Fig. 1. Cotton Yields with (a) Rate and (b) Date of Nitrogenous Fertilizer Application. (5 Separate Seasons)

Fertilizer Application. (5 Separate Seasons)

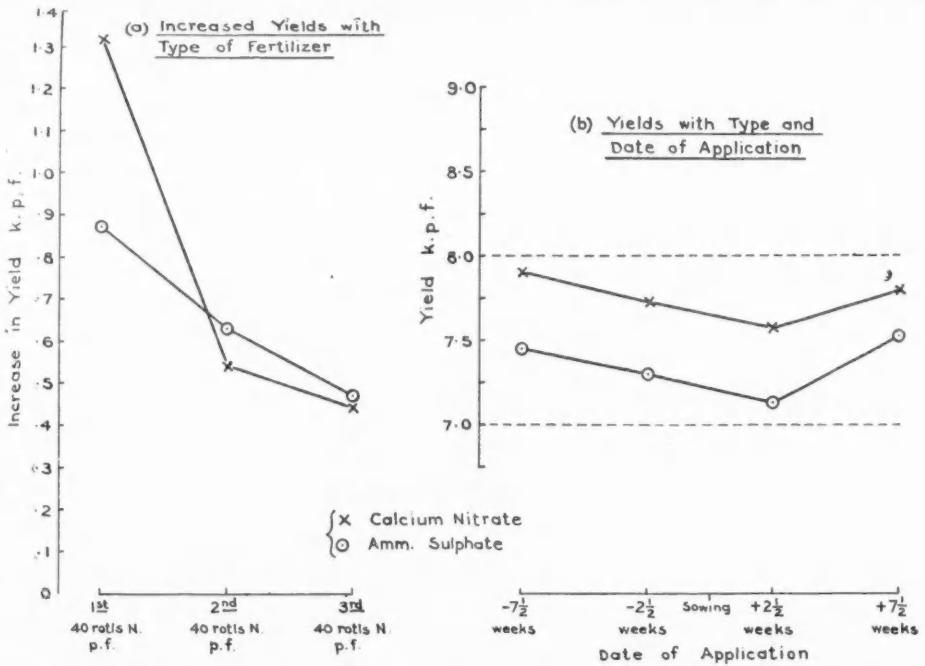

Fig. 2. (a) Increased Yields with Type and Rate of Fertilizer Application.
(b) Yields with Type and Date of Fertilizer Application.
(Both average of 5 Seasons' Results)

ammonia, at higher rates the additional yield per unit N *was as great with the ammonia fertilizer as with the nitrate.*

Regarding individual seasons, in four of the five years the curves for

TABLE 2. *Yields with Different Types and Amounts of Nitrogen*

Type	*Kantars per feddan*					
	1935–6	*1936–7*	*1937–8*	*1938–9*	*1939–40*	*Average*
Calcium nitrate 1N	7·10	7·60	7·17	8·43	5·80	7·22
2N	7·53	8·65	7·25	8·99	6·57	7·80
3N	7·80	9·20	7·92	9·34	6·93	8·24
Ammonium sulphate 1N	6·26	6·92	6·98	8·15	5·56	6·77
2N	6·80	8·12	6·84	9·02	6·18	7·39
3N	7·58	8·32	7·51	9·26	6·66	7·87
Means						
No nitrogen . .	5·27	5·87	6·37	7·03	4·93	5·89
Calcium nitrate . .	7·48	8·48	7·45	8·92	6·43	7·75
Ammonium sulphate .	6·88	7·79	7·11	8·81	6·13	7·34
Additional increase with calcium nitrate . .	+0·60	+0·69	+0·34	+0·11	+0·30	+0·41
Standard error of additional increase . .	±0·150**	±0·144**	±0·150*	±0·226	±0·086**	±0·050**

* The asterisks above standard errors in this and subsequent tables refer to significance by the 'Z' tests. Those with one are significant at the 5 per cent. and with two at the 1 per cent. level.

the response of the two types to increasing amounts of fertilizer differed significantly. These differences were all caused primarily by the large response to nitrate at the lowest rate (see Table 3, where the separate years are tabulated):

TABLE 3. *Yield-Increases with Calcium Nitrate as Percentage of those with Ammonium Sulphate*

Year	(*a*) 0N *to* 1N	(*b*) *Average* 1N *to* 2N *and* 2N *to* 3N
	Per cent.	Per cent.
1935–6	186	53
1936–7	165	114
1937–8	132	141
1938–9	125	82
1939–40	138	103
Average	149	99

In four years the superiority of nitrate was most pronounced at the lowest rate of application. In the other year, 1937–8, the response to nitrogen was small under all conditions.

Considering the total increases, the advantage of the nitrate over the ammonia fertilizer fell, of course, as the dressings became heavier. The yields given by 1N, 2N, and 3N of ammonium sulphate were found by interpolation to equal those given by 52, 64, and 71 per cent. respectively of the same amount of nitrogen as calcium nitrate.

Date of fertilizer application.—The optimum date of application appeared to be the same for both types of fertilizer (Fig. 2*b*), and there were no significant interactions in any season. In consequence, the combined data for both types have been used in further examination of the optimum date of application.

The yields for the separate years are plotted in Fig. 1*b*, the three amounts being averaged. There was considerable variation from year to year, and this is emphasized in the analysis of variance for 'Date of application', the treatment being expressed in terms (multiples) of the error variance, as follows:

	Date of application				
Degrees of freedom	*1935–6*	*1936–7*	*1937–8*	*1938–9*	*1939–40*
Regression 1 . .	1·7	6·5*	0·5	0·9	17·8**
Quadratic 1 . .	3·0	1·5	2·3	..	20·1**
Cubic 1 . .	1·3	1·1	2·2	..	0·8

Date of application was significant in two years only. In one case the earliest date was optimal, in the other, the latest date. Despite this wide variation some generalizations for the five seasons are possible. There are two periods (Fig. 2*b*) of which either or both may be optimal in any year. Within the limits of the experiment one period falls in June and the other in October, but, since extremes were not investigated, the one may be *before* June and the other *after* October. Of the five seasons examined, the greatest increases were obtained in three years with June applications and in two years with October applications. *Maximum increases were in no season obtained with applications near sowing-time, that is, from late July to early September.* Shortly after sowing appears to be the least successful date of all.

At present it is impossible to forecast which of the two periods will be optimal in any year. Of the five seasons, those with a high average yield tended to favour early applications, and those with a low average yield, late applications; but the run of seasons is too short to justify generalization. In any case a season which is to produce a high average yield is not recognizable before September [9], which is too late to alter date of fertilizer application.

It has been shown that these conclusions are unaffected by the *type* of fertilizer used. Table 4 shows that they hold also irrespective of *amount* of fertilizer. Yield-increases (over 0N plots) for the separate dates are expressed as percentages of the average, for each rate.

TABLE 4. *Yield-Increases from Rates and Dates of Application (expressed as percentage of mean increase with each rate)*

	Date of application			
Rates	*−7½ weeks*	*−2½ weeks*	*+2½ weeks*	*+7½ weeks*
1N	112·7	92·7	87·3	106·4
2N	105·3	95·3	91·2	107·1
3N	102·3	104·6	85·2	106·9

Large quantities of fertilizer might be expected to be more effective if applied early, to give longer time for absorption, but of this there is no sign.

Discussion

The most important result from the experiment is the regular superiority of the nitrate fertilizer over the ammonia type. This had not been suspected in the Gezira, and, since existing practice employs ammonium sulphate only, the experiment suggests a possible modification of the manurial programme. In Egypt, too, experimental evidence refutes common agricultural practice, but there, strangely enough, the story is reversed. A nitrate fertilizer is almost invariably used for the cotton crop, yet Gracie and Khalil [10], for example, state: 'From numerous trials carried out on the point it makes no *immediate* difference whether the nitrogen is supplied in the form of nitrate of soda, calcium nitrate, nitro-chalk, or sulphate of ammonia, etc.'

The problem of nitrate superiority in the Gezira may be examined from two standpoints, the enhanced efficacy of nitrate and the reduced efficiency of ammonia, as sources of nitrogen. The form of the yield-curves suggests a special merit in the nitrate.

It is possible that the cotton plant in the Gezira may experience a specific need of nitrate, in addition to the usual demand for nitrogen in any form. If such need exists it is for a small amount only, since it is met by the lowest rate of nitrate manuring (Fig. 2*a*), further additions of the nitrate and the ammonia fertilizer proving equally efficacious.

But such a specific need for nitrate would hardly show up with applications at two months before sowing, for in those two months appreciable nitrification of the ammonium sulphate will have taken place and by the time the cotton is sown the two types of fertilizer will both be supplying nitrogen in the nitrate form.

The calcium-content of the nitrate fertilizer must not be overlooked, for little is known of the effect of small amounts of soluble calcium salts on alkaline sodium-soils, such as those of the Gezira.

Reduced efficiency of ammonium sulphate could arise from several causes. The ammonium salts, present in high concentration, might react with the alkaline soil to lose gaseous ammonia. Or ammonia might be held by the clay complex so as to become unavailable, at least temporarily. In both cases the nitrate would be unaffected.

Since any reduced efficiency of ammonia is limited to the first unit of fertilizer, the loss or immobilizing of ammonia must be strictly localized, operating, possibly, only with high concentration of salts, such as occurs near the soil surface soon after the application of the fertilizer. An estimate of the amount of nitrogen probably involved can be made from the corresponding increases for calcium nitrate. Whereas the second and third units of ammonium sulphate give yield-increases similar to those with calcium nitrate (Fig. 2*a*), the first unit gives an increase corresponding to only a half-unit of calcium nitrate. Thus about 20 lb. nitrogen per acre appear to be lost or immobilized when ammonium sulphate is used instead of calcium nitrate. Hence, on this

interpretation, any fixed amount of ammonium sulphate is less effective by 20 lb. nitrogen per acre than the same amount of calcium nitrate, measured by nitrogen-content.

Reduced efficiency of ammonium sulphate is possible also through microbiological agencies, for organisms capable of liberating gaseous ammonia and nitrogen have been isolated by the Botany and Plant Pathology Section of this Institute. But as yet little is known, and, moreover, since denitrifying organisms occur as well, it is difficult to understand why nitrate fertilizer should not suffer equally.

At present, information is lacking for a critical test of these possible explanations. A solution of the problem is of more than purely academic interest because the fate of fertilizer not absorbed by the cotton crop may ultimately determine the choice of fertilizer. Here, fertilizer residuals, as measured by their recovery in succeeding sorghum and other crops, will show at once whether the nitrogen is lost or merely locked up temporarily when ammonium sulphate is applied. Residual effects from ammonium sulphate are known to be appreciable, but unfortunately few data on residual effects are available for the plots of this experiment. That nitrogen is not readily lost from Gezira soil, even under the worst conditions, is suggested by the results of a waterlogging experiment given later.

The 'Date of application' results are at variance with common experience in other countries. In Europe, highly soluble nitrogenous fertilizers are applied as top-dressings several months after crops are sown. Even in Egypt, where, superficially, conditions resemble those of the Sudan Gezira, applications to cotton are made at thinning-time, 6 to 8 weeks after sowing. This optimum date before sowing appears to be without parallel.

Seven and a half weeks before sowing means late June. Examination of the rainfall records for the five seasons shows that on an average 59 per cent. of the annual rainfall, or about 10 in., occurred during those $7\frac{1}{2}$ weeks. The success of the early applications shows that they cannot be subjected to severe leaching downwards or washing off the surface. Restricted leaching is consistent with the nature of the soil, where water-movement downwards proceeds so slowly that only a small proportion penetrates below 2 ft., even when water remains standing on the surface for several weeks [11, 12].

The large increases with early applications show not only that leaching is unimportant, but also that loss of nitrogen through denitrification cannot be great, though waterlogging of the top soil is frequent during the rainy season. This is supported by the results of another experiment at Gezira Research Farm which examined the retention of fertilizer under conditions of severe waterlogging. In it the waterlogging associated with rainfall was intensified by irrigating the land on successive days during the main rain-period (Table 5). The manure was 300 lb. ammonium sulphate per acre applied to all treatments on July 20 before waterlogging began.

Fertilizer response was considerable and not greatly altered by waterlogging. Thus fertilizers once applied are not appreciably disturbed by

leaching or by waterlogging agencies. Heavy rains falling soon after sowing cannot therefore be held responsible for the smaller increases with applications made around sowing-time.

The persistence of fertilizers explains why there is no loss of nitrogen from the earliest application, but it does not account for the advantage of an early application over those nearer sowing-time. Here the suggestion is offered that early applications, made before the rains have set in, benefit by the extensive soil cracking which characterizes all fallow land at this season. The low permeability of Gezira soil greatly retards the downwards movement of water and presumably of salts [11]. But under

TABLE 5. *Cotton Yields with Manuring and Waterlogging* (*1939–1940*)

(Variety: X 1730A; Area: 5 feddans; Replicates: 5)

Kantars per feddan

Treatment	*Unmanured*	*Manured*	*Increase from manure*
1. Control	4·84	6·23	+1·39
2. Waterlogging 7 days in Aug.	5·29	6·23	+0·94
3. Waterlogging 21 days in July–Aug.	5·96	7·19	+1·23

Standard errors (*a*) Within rows = 0·174**
(*b*) Within columns = 0·473

desiccating conditions profuse cracking takes place and penetrates on an average to a depth of 20 in. During the main growing-period the zone of the greatest root-activity is about one foot below the surface [13]. Thus fertilizer applications made in June, on extensively cracked soil, are dissolved and flushed down by succeeding showers, to a soil layer which later will be occupied by cotton roots.

Early applications therefore become effectively *deep* applications, in contrast to those made around sowing-time, which, because the cracks have been closed by the heavy rains, remain nearer the surface.

This interpretation is supported by the results of another experiment where fertilizers were applied shortly *after* sowing but at varying depths. Holes were made by a soil-borer at regular intervals along the furrows, and soil was rammed down after the fertilizer to avoid improved water-penetration. The results are given in Table 6.

The application of ammonium sulphate was at the rate of 400 lb. per acre in all cases.

Surface-application gave considerable increase in yield but *application at 6 in. depth gave double the increase of the surface-application.* Applications deeper than 6 in. did not differ significantly from those at 6 in. These results are from early September applications. It is suggested that surface-applications made in June, on cracked soil, would by sowing-time have penetrated to a depth corresponding roughly to the deep applications of the above experiment.

The interpretation, that applications made on cracked land benefit by becoming deep applications, can be extended equally well to the late optimum, for after the main rain-period the weather is hot and the

soil cracks considerably between irrigations. Observations on cotton-land show that the cracks during October extend to a depth of at least 12 in. Applications during the rain-period are less effective because the formation of cracks is impeded by the frequent rainstorms, the generally humid conditions, and by the limited root-absorption of the crop in its early stages.

TABLE 6. *Yields with Fertilizers applied at Various Depths (1939–1940)*

(Variety: X 1730A; Sown: Aug. 19; Fertilizer applied: Sept. 1–4)

Area: ¼ feddan; Replicates: 3

Kantars per feddan

Treatment	*Yield*	*Increase*
1. Unmanured	3·58	..
2. Fertilizer on surface	4·50	+0·92
3. Fertilizer at 6 in. depth	5·48	+1·90
4. Fertilizer at 12 in. depth	5·60	+2·02
5. Fertilizer at 18 in. depth	5·57	+1·99
6. Fertilizer at 24 in. depth	5·91	+2·33

Standard error = 0·221**

Summary and Conclusions

Considering only the cotton crop to which the fertilizer is applied, calcium nitrate gives a greater yield-increase than ammonium sulphate in the Gezira. This is particularly true of light dressings of about 38 lb. N per acre, for then the increase from calcium nitrate may be as great as 50 per cent. over that from ammonium sulphate, which more than compensates for the former's extra cost per unit of nitrogen. When the reasons for this superiority are understood it will be possible to formulate further recommendations. For instance, if it results from a specific need of the cotton for nitrate, then a mixed dressing may be preferable, of calcium nitrate to satisfy this need and ammonium sulphate as a cheaper form of nitrogen; or nitro-chalk, containing ammonium nitrate, may be preferred. If, however, a fixed amount of ammonium sulphate is rendered useless, there is no merit in a mixed application, and ammonium sulphate must be used only for heavy dressings, when its lower cost compensates for its lower efficiency.

In selecting a fertilizer, residual effects cannot be ignored. From the scant experimental evidence at present available there is nothing to suggest that they are less from calcium nitrate than from ammonium sulphate, and thus nothing yet to modify the conclusion about the superiority of calcium nitrate. But more experimental work on residual effects is necessary before recommendations are offered for replacing ammonium sulphate by calcium nitrate in general agricultural practice in the Sudan Gezira.

As far as information goes, fertilizers should be applied in either June or October for cotton sown at the normal time, early August. Some years June applications will prove a little more successful than October and vice versa. It may be found profitable to split all dressings, giving

half in June and half in October, but this has not yet been tested by experiment. Evidence is advanced to suggest that the greater efficiency of nitrogenous fertilizers applied before or after the rains is due to the more extensive cracking of the soil and the better penetration of nitrate.

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COMPARATIVE LABOUR EFFICIENCY IN AGRICULTURE

O. J. BEILBY

THE efficiency of labour in producing goods is obviously a factor which determines the standard of living. In a primitive community possession of material goods depended quite literally on man's willingness to work and produce those goods. In the modern economic system this direct relationship between work and wealth is somewhat obscured by the introduction of a monetary system and by the division of labour, but it nevertheless must ultimately remain true of the community as a whole.

This proposition does not necessarily hold good for a part of the community such as the agricultural population. Agriculture may be subsidized, or protected by means of tariffs, quotas, marketing schemes and the like, so that the rest of the community may be maintaining the standard of living of agriculturists at a higher level than strict competitive conditions would permit. It may be said to be broadly true, however, that only by raising the efficiency of their labour can agriculturists raise their standard of living.

It is well known that standards of living vary greatly in the different countries of the world and this might be expected to be the result of differences in the efficiency of labour. This paper, therefore, is an attempt to bring together some statistical information on the efficiency of agricultural labour in some of the more important countries.

One way of measuring the efficiency of agricultural labour is to estimate how many people each agricultural worker can feed. The more he can feed, the more man-power is set free to produce things other than food. Another method is to measure the value of the output of each worker. If a worker can produce x tons of wheat a year, he may be said to be twice as efficient as one producing $\frac{x}{2}$ tons per year. The calculation of the agricultural output in any country is not easy. This output consists of a variety of animal and vegetable products which are measured in different physical units that cannot be added directly together until they are converted to a common denominator, such as money or calories.

Persons fed per agricultural worker.—Estimates of the number of persons *occupied* in agriculture have been made from time to time in most countries, but unfortunately the results are often far from comparable. In peasant countries it is particularly hard to enumerate the number engaged in agriculture, where members of the family may be partly engaged in domestic work and partly on farm work. In all countries there is the problem of allowing for seasonal employment, which is very widespread. The figures given in Table 2 are the best that are available, though it would not be claimed that they are comparable in all respects. They are mostly derived from recent population censuses.

The number of persons *fed* by agriculture cannot, in most countries, be obtained directly. Part of the food supply may be exported or imported. A preliminary calculation has, however, been made in Table 1

of the extent to which certain countries are self-sufficient in their food supplies, making allowance for imports and exports of food. The result is expressed as a percentage; 100 per cent. would indicate that a country was just self-sufficient, any imports of food being balanced by corresponding exports. Thus, Canada with a percentage of 126 can feed, from her own soil, a population 26 per cent. greater than she actually possesses, whereas Britain can feed only 38 per cent. of her population from her own agricultural output. New Zealand and Australia have by far the largest exportable surplus, whilst the United States, though a considerable exporter of food, also imports large quantities, and is, on balance, not very much more than self-supporting.

TABLE 1. *Self-sufficiency in Food Supplies in Six Countries*

Country	*Period*	*Unit of currency*	*Home production*	*Exports and re-exports*	*Imports*	*Home consumption*	*Production as per cent. of consumption*
New Zealand .	1935–7	N.Z. £000	80,500	58,670	4,000	25,830	312
Australia .	1935–7	A. £000	191,250	116,650	7,900	82,500	232
Eire . .	1937–8	£000	41,830	18,250	7,300	30,880	135
Canada . .	1936–8	$000	700,105	231,176	84,859	553,788	126
United States .	1935–7	$000	9,186,000	772,166	571,359	8,985,193	102
Great Britain*.	1937–8	£000	210,000	14,500	348,500	544,000	38

* Includes England, Wales, and Scotland.

SOURCES AND NOTES.

NEW ZEALAND. *New Zealand Year Book*, 1939, pp. 805, 890, 910. Home production is taken as 'net production' valued at wholesale prices in main marketing centres and relates to the years 1935–6 and 1936–7. Imports and exports are for the years 1935, 1936, and 1937.

AUSTRALIA. *Australia Year Book*, 1938, pp. 524, 528, 959. Home production is taken as the net value of production valued at wholesale markets, i.e. the net value at the farm as given in the *Year Book*, plus marketing costs.

EIRE. *Irish Trade Journal and Statistical Bulletin*, March 1939, p. 25, and September 1939, pp. 134–8. Home production is taken as the net output of agriculture, i.e. the gross output less purchases of feeding-stuffs, fertilizers, &c. Imports include the value of imported feeding-stuffs.

CANADA. *Canada Year Book*, 1939, pp. 178, 513, 527, and 1169, and 1940, p. 1156. The net value of production allows for the cost of seed and feed, but not for fertilizers. Exports include food, plus hay, seeds, and animals; imports are for food, less tea, coffee, and hops.

UNITED STATES. *U.S.A. Agricultural Statistics*, 1939, pp. 430, 482. The value of home production includes the cash farm income from sale of crops, live stock, and live-stock products, plus the value of commodities consumed on the farms where grown, valued at average prices received by farmers for commodities sold. The average of the three-year period 1935, 1936, 1937 was chosen, as neither 1936 nor 1937 by itself can be considered as normal.

GREAT BRITAIN. Imports and exports of food from *Monthly Trade and Navigation Accounts*. Home production is the net output of agriculture, i.e. the gross output as given in the official Agricultural Statistics, less the value of feeding-stuffs and fertilizers either imported or made from imported materials. The latter were taken from the *Monthly Trade and Navigation Accounts* and the results of the Census of Production, 1935, published in the *Board of Trade Journal*. The value of imported feeding-stuffs is included in 'imports'.

In Table 2 the actual population of each country has been adjusted

by these percentage figures. The 'adjusted' population is then divided by the number of farm workers to give the population fed per worker.

TABLE 2. *Number of People supported per Agricultural Worker*

Country	*Population at 31.12.37* (1)	*Self-sufficiency in food supplies* (2) *per cent.*	*'Adjusted' population*	*No. occupied in farming* (3)	*No. of people fed per worker*
New Zealand .	1,600,000	312	4,992,000	152,400	33
Australia . .	6,870,000	232	15,938,000	547,800	29
Great Britain .	46,100,000	38	17,518,000	1,030,000	17
Netherlands .	8,600,000	116	9,776,000	630,000	16
United States .	129,800,000	102	132,400,000	10,170,000	13
Canada . .	11,160,000	126	14,061,600	1,132,000	12
Denmark . .	3,760,000	168	6,317,000	510,000	12
Belgium . .	8,400,000	67	5,628,000	640,000	9
Germany . .	68,000,000	89	60,520,000	9,000,000	7
Switzerland .	4,200,000	77	3,234,000	480,000	7
Eire . .	2,940,000	135	3,970,000	644,000	6
France . .	42,000,000	91	38,220,000	7,300,000	5

SOURCES AND NOTES.

(1) From *Statistical Year Book of League of Nations*, 1938–9, pp. 16–19.

(2) See Table 1. Figures for the six European countries are calculated from data kindly supplied by Mr. P. Lamartine Yates.

(3) Belgium, Switzerland, Germany, France, Netherlands, and Denmark from *Food Production in Western Europe*, by P. Lamartine Yates, p. 527, Longmans, Green & Co., 1940; New Zealand from *New Zealand Year Book*, 1939, p. 950; Australia from *Australia Year Book*, 1939, p. 353; Canada from *Canada Year Book*, 1937, p. 132; United States from the *1930 Census of Population*, vol. iv, p. 17, when the number of workers was 10,472,000—it is officially estimated to have fallen by 300,000 since then; Eire from the *Irish Trade Journal and Statistical Bulletin*, September 1939, p. 167; Great Britain, the number of farm workers from *Agricultural Statistics* (England and Wales), 1938, p. 41, and *Agricultural Statistics* (Scotland), 1938, p. 27; the number of farmers in Great Britain is estimated at 335,000.

On this basis the agricultural worker in New Zealand is seen to feed 33 people, and in Australia 29 people. Great Britain comes next on the list, but each worker feeds only 17 people or but little over half the number in New Zealand. Great Britain, however, compares favourably with the remaining countries. In the Netherlands, the United States, Canada, and Denmark each worker feeds from 12 to 16 people. The countries that are left are all European, and in them the peasant type of agriculture prevails; the number of people fed per worker is low, varying from only 5 in France, to 9 in Belgium.

Value of output per worker. Table 3 shows the alternative method of calculating the comparative efficiency of labour, i.e. by measuring the value of the output per worker. It is the net output per worker that is shown, net output being defined as the output of crops, live stock, and live-stock produce less the value of fertilizers and imported feeding-stuffs used to produce this output. It thus represents the net addition to the country's production attributable to agriculture. Generally, the

output has been valued at wholesale or market prices. Gross output, where given, refers to the total output of crops, live stock, and live-stock products for human consumption.

It should be noted that the output of agriculture is not necessarily synonymous with the output of food. In almost all these countries there is some production of wool, for instance, and this has been included in the output figures. In the United States the output of tobacco and cotton is also included. In many ways it would have been desirable to exclude these products, as the economic conditions under which they are produced in the Southern States of America are very different from farther north. Though the value of these crops could easily have been deducted from the total, it would have been impossible to differentiate the labour devoted to growing them from the labour producing other crops for food, so they have had to be included. The effect that this may have on the results for the United States as a whole are referred to at a later stage in this paper.

TABLE 3. *Value of Output per Worker in Six Countries*

Country	*Year*	*Gross output*	*Net output*	*Number of workers*	*Net output per worker*
		£000	£000	No.	£
New Zealand .	1936–7	70,880	68,480	152,400	450
Australia . .	1936–7	..	164,001	547,800	300
Great Britain .	1937–8	264,900	210,000	1,030,000	205
United States .	1937, 1938	1,937,000	1,888,000	10,150,000	185
Canada . .	1937–8	..	152,700	1,130,000	135
Eire . . .	1937–8	49,662	41,830	644,000	65

SOURCES AND NOTES.

Value of gross and net output from Table 1; number of workers from Table 2; output converted to £ sterling at exchange rates given in the *Statistical Year Book of the League of Nations*, 1938–9, p. 226.

New Zealand again appears at the top of the table with an output per worker of £450, whereas the corresponding figure in Australia, which comes next, is £300, or only two-thirds that of New Zealand. Great Britain and the United States are around £200, but Canada is surprisingly low at £135 and Eire has only £65. For purposes of comparison, figures of net output per worker calculated by Mr. P. Lamartine Yates for six European countries may be quoted[1]; they are £155 in Denmark, £120 in the Netherlands, £100 in Belgium, £100 in Switzerland, £90 in Germany, and £70 in France.

Comparative results.—The two alternative methods of measuring the efficiency of labour in agriculture give, on the whole, remarkably similar results. These are compared in Table 4.

It is significant that the position of the first three countries should be the same by both methods, and of the remainder only Holland is placed in a significantly different position. Nevertheless, in making a comparative study a number of factors must be borne in mind.

[1] *Food Production in Western Europe*, p. 528.

First, the two methods are not measuring exactly the same thing. Apart from the point, already discussed, that the output figures, notably for the United States, include products that are not food, the number of persons that can be fed by a given output of food depends on the relative standards of living. The higher the standard of living the fewer the people who can be fed from a given output. Some idea of the value per head of food produced and imported may be obtained from the figures of 'home consumption' in Table 1, and of population in Table 2. Very approximately, it appears that whereas the value of food consumed in the

TABLE 4. *Countries arranged according to Relative Labour Efficiency*

	Persons fed per worker	*Net output per worker*
1	New Zealand	New Zealand
2	Australia	Australia
3	Great Britain	Great Britain
4	Netherlands	United States
5	United States	Denmark
6	Canada	Canada
7	Denmark	Netherlands
8	Belgium	Belgium
9	Switzerland	Switzerland
10	Germany	France
11	Eire	Germany
12	France	Eire

United States was equivalent to £14 per head per annum, in New Zealand it was £13, in Britain £12, in Australia, Canada, and Eire £10.[1] These figures probably give a fair guide to the relative standard of living in these countries. The high standard of living in the United States, for instance, may account for the relatively lower position of that country when measured by persons fed rather than by output per worker.

Secondly, the value of output per worker is affected by the level of agricultural prices. A straight comparison, as made in Table 4, really assumes a world agricultural price-level. The position is complicated by tariffs on agricultural products in food-importing countries, and by the bounties paid in some exporting countries: for perishable products, such as milk, which are not the subject of international trade, price-levels may show considerable permanent differences. The general evidence would seem to point to France and Switzerland as being countries in which farm prices are higher than elsewhere, but prices in Britain must also be considered relatively high, and are probably, on the average, higher than in the remaining countries.

Thirdly, the doubtful comparability of the statistics of the number of workers must be borne in mind. This affects both methods of measurement and may be due partly to differences in census classifications. In some of the European countries it is possible that the figures include a

[1] Values at wholesale prices, excluding fish and drink. The amounts actually *spent* on food would, of course, be considerably higher than these, as the costs of processing and manufacturing most foodstuffs, as well as the costs of retailing, would have to be added.

number of women who are mainly occupied in domestic work. Certainly the proportion of women workers in the countries of continental Europe, particularly Germany, is much higher than elsewhere. Whereas for every 100 men employed, in Germany there are 99 women, and in France 70 women, in Britain there are only 14 women, and in New Zealand and Australia only 4.

Fourthly, the extent to which farm produce consumed in the farm household is included in the agricultural output is not known in all countries. In Britain, U.S.A., and Eire it is definitely included, but it may not be so in Australia and Canada. (This may partly account for the low figure of output per worker in Canada.)

Of these main qualifications to the statistics the most important is the third, viz. the doubtful comparability of the labour statistics. This is the more unfortunate, in that it affects both methods of calculation. These qualifications must be borne in mind in studying the figures. It seems unlikely, however, that the general position of the respective countries would be substantially affected if more accurate figures were available.

Relation of output per worker to other economic factors.—It may be of interest to compare the output per worker with (*a*) the intensity of cultivation, measured by the output per 100 acres, and (*b*) the density of employment, measured by the number of workers per 100 acres.

TABLE 5. *Comparison of Output per Worker with Intensity of Cultivation and Density of Employment*

	Area of cultivated land (1)	*Value of output per 100 acres*	*Number of workers per 100 acres*	*Value of output per worker*
	000 acres	£	No.	£
New Zealand . .	18,762	365	0·8	450
Australia . . .	37,146	442	1·5	300
Great Britain (2) . .	29,106	721	3·5	205
United States (3) . .	889,338	212	1·1	185
Denmark . . .	7,608	1,038	6·7	155
Canada (3) . . .	66,299	235	1·7	135
Netherlands . . .	5,599	1,413	11·4	120
Belgium . . .	4,369	1,350	14·6	100
Switzerland (3) . .	5,394	945	8·9	100
France	80,606	782	9·0	90
Germany . . .	68,983	855	13·0	70
Eire	11,594	361	5·6	65

SOURCES AND NOTES.

(1) Total of arable land and permanent pasture from *International Year Book of Agricultural Statistics*, 1937–8.

(2) Acreage excludes rough grazings.

(3) The acreage figures for the United States, Canada, and Switzerland include considerable areas of unimproved pasture, from which only a small output will be obtained. This makes the output and the number of workers per 100 acres in these countries lower than it should be for purposes of comparison with the remainder.

These figures show clearly that there is little relation between the output per worker and the output per 100 acres. When the output per worker is compared with the density of employment the relationship is,

on the whole, an inverse one. New Zealand, with the lowest density of employment, 0·8 workers per 100 acres, has by far the highest output per man, whilst most of the European countries with a high output per 100 acres have a relatively low output per worker.

Conclusions.—The result of these calculations is to show that the countries considered in this paper may be divided roughly into three groups so far as the efficiency of labour is concerned.

First, New Zealand and Australia are in a class by themselves with an extremely high efficiency of labour. To discover the exact reasons for the high productivity of labour in these countries would require much research into their systems of farming and agricultural production. Various contributory factors may, however, be suggested such as the relative plentifulness of land and shortage of labour, the high average standard of living of the population, the dependence of the economic life of these countries on the export of foodstuffs, the high degree of mechanization and, in New Zealand, probably also the favourable climate.

The second group of countries comprises Great Britain, the United States, Denmark, Canada, and Holland. The last three of these are again countries largely dependent, from the economic point of view, on the export of agricultural products. If agriculture is the main basis of their economic life, it must be efficient in its use of labour, for, on this, the standard of living of the whole community largely depends.

In Britain, however, agriculture, though one of the larger individual industries, plays a relatively less important part in the nation's economic life. The standard of living depends mainly on the output per worker in industry, which is somewhat higher than in agriculture.[1] This difference is nevertheless one which may call for difficult internal social adjustments between industry and agriculture.

The United States, though it has a not inconsiderable export trade in agricultural products, is, in relation to its size, a self-sufficient country agriculturally. The figures presented for the United States are perhaps rather misleading, because such a vast country cannot really be regarded as a homogeneous unit from the agricultural point of view. Great differences exist between regions such as the cotton-belt in the south with its large preponderance of negro workers, the specialized fruit-growing in California, the large mixed farms of the corn-belt, and the small mixed farms in the New England states. The average figure of output per worker is certainly considerably lowered by the first of these groups, and probably also by the last. The average output per worker in the corn-belt states of the middle west, and in the western states, is almost certainly higher than in Britain,[2] and probably approaches the level of Australia and New Zealand.

[1] The average net output per worker in industry was £223 in 1935; see Supplement to the *Board of Trade Journal*, Dec. 23, 1937, pp. iii and iv. Owing to the higher price-level this figure had probably increased by 1937, when output per head may be estimated at from £25–30 greater than in agriculture.

[2] The output per head of *farm population* (some 3 or 4 times greater than the number of *workers*) varied from £26 in South Carolina, one of the major cotton-belt states, to £125 in Iowa, and £175 in California. It may be estimated, very roughly, that the output per worker varied from £70–90 in South Carolina to £400–600 in California.

The third group of countries are all European and have many features differing from those of the New World. All consist largely of peasant farmers, cultivating small plots of land intensively, mainly with the aid of a dense agricultural population rather than by employing machinery. In some of these countries, such as France and Switzerland, agriculture is highly protected and is insulated from the effects of world competition. Since it is unlikely that the land could be much more intensively cultivated than at present, the output per worker could only be increased by a drastic reduction in the agricultural population. Such a step is probably unthinkable to the governments of most of these countries, for it would mean the disruption of the peasant system, which has been the basis of their social life for centuries. Part of the agricultural policy of Nazi Germany, for instance, has been the exaltation of the peasant way of life above all others. Despite this, there appears to have been a considerable reduction in the number of people employed in agriculture in Germany in the last five years,[1] but this is the result of the demand for labour in munition factories and the army, which it may be hoped are not to be regarded as normal peace-time influences.

It has only been possible in this paper to touch on some of the factors affecting the productivity of labour in different countries. In New Zealand, labour in agriculture is used much more efficiently than in any of the other countries considered,[2] whilst in the peasant countries of Europe its efficiency is much less than elsewhere. At the same time it would be wrong to conclude that methods of farming practised in New Zealand should necessarily be adopted in Europe. The organization of agriculture is closely interwoven with the whole social fabric, and a change in the one must involve a change in the other. It has been suggested that only by an appreciable reduction in the labour employed in the peasant countries of Europe will the output per worker be raised. It may be that the social structure of society is too rigid to admit of any large reorganization of agricultural methods, which might well involve the enlargement and amalgamation of farms, the necessity of replacing existing capital equipment, and, in general, too great an interference with established ways of life. Even in Great Britain, where the net output per worker may be estimated to have increased from £150 in 1925 to £205 in 1937, the time may soon come when any further increase in output per worker can be achieved only by radical changes in the social structure of the rural community—a change which may partially be brought about as a result of the war-time control of production. Nevertheless, one of the primary aims of agricultural policy in all countries must remain that of securing the best possible standard of living for all agricultural workers. All questions of size of holdings, of workers employed, and of necessary capital equipment should be considered from this standpoint.

[1] Mr. P. Lamartine Yates estimates that 'not far short of one million workers left the land' between 1935 and 1939. Cf. *Food Production in Western Europe*, p. 443.

[2] Excepting, possibly, certain parts of the United States.

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PINING IN SHEEP: ITS CONTROL BY ADMINISTRATION OF COBALT AND BY USE OF COBALT-RICH FERTILIZERS

JAMES STEWART

(*Animal Diseases Research Association, Moredun Institute, Gilmerton, Edinburgh*)

AND

R. L. MITCHELL AND A. B. STEWART

(*The Macaulay Institute for Soil Research, Aberdeen*)

Introduction.—Although many workers in Australia and New Zealand have shown that pining in stock can be cured and prevented by administering minute quantities of cobalt, research workers in Great Britain have adduced few experimental data either to show that the conditions of 'pine' are identical with those found in New Zealand and Australia, or that the addition of cobalt to the diet will prevent or cure the disease. The experiments of Corner and Smith [1], conducted in S.E. Scotland, showed that pining in that district could be cured and prevented for six months by dosing with 1 mg. of cobalt per day for fourteen days. They stated that the beneficial effects obtained previously by feeding iron salts were due to the cobalt-content of the iron compounds used. The experimental data recorded in their paper did not show any marked difference between the cobalt-contents of the soil and pasture from 'pining' farms, and those given for 'non-pining' areas. Moreover, in the experiments referred to as having been previously successful owing to the cobalt-content of the iron salts, the majority of the animals showed recovery with a daily dose of 3·9 gm. iron ammonium citrate, and since this salt contained only 9 p.p.m. cobalt, the lambs were receiving only 0·035 mg. per day or 0·73 mg. cobalt in the three weeks on experiment. So far, no other workers have suggested that such a small dose would be sufficient either to prevent or cure the disease. It is admitted that iron oxide containing 50 p.p.m. cobalt might supply sufficient cobalt to allow of an intake of 1 mg. cobalt per day but, as has been previously noted, only a small group of the experimental lambs was receiving this form of iron treatment (Greig *et al.*) [2]. Therefore, at the present stage of our knowledge, it cannot be maintained that the whole benefit of the iron treatment was due to the cobalt-content of the iron salts.

Control by Administration of Cobalt Salts

During the past three years the soils of pining-farms in Ross-shire, Inverness-shire, and Sutherland-shire have been systematically examined. The number of soils so far examined is still too small to justify publication of a statistical analysis of the results, but it can now

be definitely stated that pining occurs on a number of farms where the soils have very low cobalt-contents. The range of cobalt-contents of all soils which have been examined spectrographically at the Macaulay Institute has been from 1 to 300 p.p.m., with a mode of approximately 10 p.p.m.; most of the pining soils have less than 5 p.p.m. Co. In many cases the soils have a lower cobalt-content than those reported from New Zealand and Australia as being typically cobalt-deficient. On one such farm in Ross-shire, five fields, on which there has been a yearly loss of sheep and cattle from 'pine', were examined and the cobalt-contents of the soils were as follows:

TABLE 1. *Cobalt-contents of Soils on a Ross-shire Farm*

Field. . .	1	2	3	4	5
Co (p.p.m.)	1·0	1·0–1·5	1·5–2·0	1·5	1·0

It was recently ascertained that the farmer, although using iron oxide as a supplement to his usual cattle feeds, did not allow his sheep access to the iron, and that every year he lost many of his lambs from a 'pining disease'. In 1938, being unable to conduct a controlled experiment, he administered cobalt solution to all his ailing lambs, and a considerable proportion recovered.

In 1939 we were enabled through the very active collaboration of Mr. C. M. Allan, Agricultural Organizer for Ross-shire, who undertook the supervision of the experiment in the field, to run a successfully controlled experiment. Towards the end of June 1939, 65 lambs were divided into two groups, one consisting of 40 lambs to be treated with cobalt, and the other of 25 to serve as a control. The 25 control lambs were the best in the flock and at the beginning of the experiment were all in excellent condition. In the group of 40 there were five lambs showing clinical signs of pining and many of the others were in poor condition. Both groups were allowed to run together on fields, which had the history of being 'bad pining fields', i.e. those of which the soil cobalt-content is shown in Table 1. The 40 experimental lambs were given 10 mg. cobalt in the form of $CoCl_2.6H_2O$ (Analar), by the mouth once a week from June 20 till September 4, i.e. each lamb received 100 mg. cobalt over a period of 10 weeks. One lamb of the treated group died 3 days after the start of the experiment; the cause of death, which was not due to pine, was not determined. The total of this group was immediately made up again to 40 by withdrawing one lamb from the control group. As the experiment progressed there was a complete reversal in the condition of the two groups. The members of the control group lost condition quickly whilst those in the treated group showed obvious signs of improvement in condition and growth. Four members of the control group died as a result of pining and on September 4 many of the others were in the last stage of the disease. In contrast, not one of the treated group lost condition. Many of them were in excellent health, and the farmer averred that he had never seen such a good set of lambs on the farm. Those which had been pining at the

beginning of the experiment now showed no clinical signs of the disease and, although not in the excellent condition of the others, were beginning to thrive. On September 4 a professional live-stock valuer assessed the difference between the two groups at 21*s.* per head, the treated lambs at 43*s.* average the controls at 22*s.* average.

Although the number of lambs in the experiment was admittedly very small, there seemed to be no doubt, owing to the very marked difference between the two groups, that the cobalt treatment had improved the condition of the pining lambs and prevented the occurrence of the disease in the healthy lambs.

Control by Use of a Cobalt-rich Fertilizer

In Australia and New Zealand various workers have shown that top-dressings of cobalt-rich fertilizers have increased the cobalt-content of the herbage significantly. Underwood and Harvey [3] find the soil and pasture in affected areas to be lower in cobalt than adjacent healthy areas, and report relatively large increases in the cobalt-content of herbage as a result of top-dressing with small amounts of cobalt acetate. In the 13th Annual Report (1939) of the Department of Scientific and Industrial Research, New Zealand, attention is drawn to the finding that success has attended the use of cobaltized fertilizers on pasture where diseases of the bush-sickness type occur, and manurial dressings of about 2 lb. cobalt chloride per acre applied to pasture have effected cures in bush-sick sheep. Observations on the cobalt-contents of soils and pastures are also recorded; e.g. in the Nelson District figures of 1 part per million cobalt in soil and 0·04 p.p.m. in pasture indicate a major cobalt-deficiency. Treatment with cobalt chloride at rates of ¼, ½, and 2 lb. per acre increased the cobalt-content of the pasture to 0·08, 0·16, and 0·37 p.p.m., respectively. Kidson and Maunsell [4] also report increases in the cobalt-content of various fodder crops as a result of top-dressing with cobalt chloride. In a review of the position in New Zealand, Rigg [5] points out that although a large number of affected soils have been found with low cobalt-contents in both soil and pasture, there is by no means always a direct relationship between the cobalt-content of the pasture and the cobalt-content of the soil.

Since it is obvious from the experiments described above that pining in Easter Ross could be cured by administration of cobalt, experiments were started on two farms in that district in order to study the effects of applications of cobalt to the soil on the composition, particularly the cobalt-content, of the pasture. It was hoped in this way to obtain information likely to be of value in the study of the question whether the application of manurial dressings of cobalt to pasture will prevent or cure pining in stock.

Plan of Manuring Experiments

As these experiments were regarded as being largely preliminary it was decided to keep the layout as simple as possible, and the following plan was adopted:

1	2	3	4	5	6
					7
4	5	1	2	3	1*a*
		4			

Treatments:

1*a*. Absolute control; no treatment. One plot of 1/100 acre.
1. Control: no cobalt, 2¼ cwt. superphosphate per acre. Two plots each 1/50 acre.
2. Half a lb. cobalt chloride ($CoCl_2.6H_2O$)+2¼ cwt. superphosphate per acre. Two plots each 1/50 acre.
3. One lb. cobalt chloride+2¼ cwt. superphosphate per acre. Two plots each 1/50 acre.
4. Two lb. cobalt chloride+2¼ cwt. superphosphate per acre. Two plots each 1/50 acre and 1 plot of ⅛ acre.
5. Ten lb. cobalt chloride+2¼ cwt. superphosphate per acre. Two plots each 1/50 acre.
6. Forty lb. cobalt chloride+2¼ cwt. superphosphate per acre. Two plots each 1/50 acre.
7. Eighty lb. cobalt chloride+2¼ cwt. superphosphate per acre. One plot of 1/200 acre.

Superphosphate was chosen as a 'filling material' for the relatively small quantities of cobalt, as it is an ingredient of most ordinary manure mixtures in which cobalt salts would likely be incorporated, if cobalt manuring were found to be successful in preventing or curing pining. In practice it is unlikely, on account of the cost of cobalt salts, that dressings much above 2 lb. per acre of cobalt chloride will prove economic. Treatments 2–4 were therefore chosen with a view to obtaining information on the minimum dressing of cobalt likely to be necessary to give an appreciable increase in the cobalt-content of pasture.

In considering cobalt manuring two main possibilities were borne in mind, viz: (1) preventive manuring, where a light dressing might be applied over a considerable area; and (2) therapeutic manuring, where the possibility of treating a relatively small area with a heavy dressing of cobalt might arise. Treatment 5, the 10 lb.-per-acre dressing, was therefore included as being more or less representative of the upper limits of probable dressings. Two small areas were chosen for treatments 6 and 7, which were included, not because they are likely to be used in practice, but in order to obtain material on which different methods of detecting cobalt in soils and pastures could be compared. Of the foregoing experimental treatments the 2 lb.-per-acre dressing is one

which has given a useful response in New Zealand, and is one which, if effective under Scottish conditions, would not entail a very heavy outlay per acre. As it was considered advisable to have available a moderate bulk of cobalt-treated herbage, which could be used if necessary in a feeding-trial, the relatively large plot of $\frac{1}{8}$ acre with the 2 lb.-per-acre dressing was included at each centre.

The treatments were applied in the middle of March 1940 on 1st-year grass intended for hay later in the season. The herbage consisted of an ordinary mixture of rye-grass, timothy, cocksfoot, and clovers. The experimental areas were fenced and stock kept off the ground, in order to avoid any risk of error arising, for instance, from contamination of untreated plots by droppings of grazing animals.

The experiments were laid down on two widely differing soil types: one formed on a raised beach and the other on Boulder Clay derived from Old Red Sandstone. Samples of soil and pasture have been taken for examination periodically throughout the summer, and it is intended to continue observations for such time as is necessary to obtain information on the duration of the effects of the cobalt dressings. Details of the methods adopted in the soil and pasture analyses, the results obtained on the raised-beach soil and for the second and subsequent samplings on the Boulder Clay soil, will be given subsequently. In the present preliminary report observations will be confined to the results obtained in the first sampling for the experiment on Old Red Sandstone, in a field adjoining that where the grazing experiment referred to below was carried out.

Preliminary examination of the soil showed that it had a pH value of 6·0 and a relatively satisfactory lime-content. The phosphate and potash supplies were likewise reasonably satisfactory, and there was an organic-matter content of approximately 8 per cent. It appeared unlikely therefore that any deficiency which might exist in the herbage would be directly associated with shortages in the major plant-food substances. The cobalt-content of the soil was found to be 2·9 p.p.m., and of this the amount soluble in dilute acetic acid, and therefore possibly representative of the amount available to plants, was 0·19 p.p.m. These figures are relatively low and a response to the application of cobalt as a manure could reasonably be expected.

At the end of May, 10 weeks after the application of the cobalt dressings, samples of the soil and pasture were taken from the individual plots. At this time it was noted that the superphosphate was showing a beneficial effect and that the cobalt dressings up to and including 40 lb. per acre had no visible effect on yield. The heavy cobalt dressing —treatment 7—had, however, markedly depressed the growth of both grasses and clovers, but as this dressing is so very much heavier than any likely to be applied, the risk in practice of depressing effects on yield from cobalt manuring would appear to be very small indeed. The cobalt figures for the soil and pasture obtained with the samples taken 10 weeks after the treatments were applied are given in Table 2.

The cobalt-content of the soil was determined colorimetrically as described by Davidson and Mitchell [6]. The readily soluble cobalt

in the soil and cobalt in the pasture were determined spectrographically by an arc method after chemical pretreatment, which will be described elsewhere.

TABLE 2. *Cobalt-contents of Soil and Pasture*

Treatment	*Co applied to soil p.p.m.*	*Co in soil p.p.m.*		*Co in pasture p.p.m.*
		Total	*Readily soluble*	
1*a*	0	2·9	0·177	0·11
1	0	2·9 2·8	0·196 0·200	0·12 0·20
2	0·06	N.D.	N.D.	0·23 0·35
3	0·125	2·9 2·9	0·215 0·230	0·34 0·41
4	0·25	3·25 3·2	0·255 0·236	0·51 0·83
5	1·25	4·0 4·2	0·479 N.D.	1·63 2·28
6	5·00	5·8	1·75	3·94
7	10·00	9·6	1·96	8·17

N.D. = not determined.

For treatments 1–5, i.e. those which were laid down in duplicate, the duplicate samplings show good agreement in total soil cobalt and in readily soluble or possibly available cobalt. Both sets of figures show distinct increases as a result of the various dressings applied. In the pasture, although the agreement between duplicate plots is less close, replicate determinations on the individual samples confirmed the results obtained: a general increase in the cobalt-content with increasing applications of cobalt. Even the 1 lb.-per-acre dressing (treatment 3) has increased the cobalt-content above the level considered satisfactory by New Zealand workers. It is evident that a 2 lb.-per-acre dressing of cobalt chloride produces a very marked increase in the cobalt-content of the pasture, and it was consequently decided to test the effect of manurial dressing at this rate on the grazing animal.

Grazing Experiment

A 6-acre field quite near the above plots was chosen for the grazing experiment. The soil in the field was similar both in origin and in general fertility. The field was divided in two halves, East and West; at the beginning of July 1940 the West half was treated with superphosphate at the rate of 3 cwt. per acre; to the East half the same quantity of superphosphate, but with cobalt at the rate of 2 lb. per acre of cobalt chloride, was applied. The cobalt figures for the soil and pasture in these areas appear in Table 3.

On August 6, i.e. 4 to 5 weeks after the field had been top-dressed, 30 lambs were selected from the flock on the farm. A professional valuer divided them into two batches of fifteen; each batch in his opinion being of equal condition and monetary value. One batch was

placed on the West half and the other on the East half of the field. On August 6 it was considered that the herbage on the West half, i.e. that dressed with superphosphate only, was slightly more luxuriant than that of the East half.

TABLE 3. *Cobalt-content of Soil and Pasture from Grazing Experiment Area before Treatment*

Area	*Co in soil p.p.m.*		*Co in pasture p.p.m.*
	Total	*Readily soluble*	
West half . .	1·7	0·115	0·090
East half . .	1·9	0·156	0·054

On this farm pining occurs early in August, and by September the lambs are usually in very poor condition. Accordingly, the lambs were allowed to graze on their respective sides of the fence until September 18. On that date a striking contrast was noticeable in the condition of the two batches of lambs. Eight of those on the West half were showing clinical symptoms of severe pining and the other seven members of this batch were poorer in condition than the worst member from the East half. The aggregate difference in live-weight between the two batches was 71 lb. in favour of the East-half batch, but the true significance of this cannot be determined since the lambs were not weighed on August 6. The valuer assessed the difference in monetary value at £10. 15*s*., and expressed his opinion that whereas every member of the East-half batch was well finished and fit to kill, not one member of the West-half batch was ready for the market. It was also of interest to observe that the cobalt-dressed half of the field was much the better grazed.

Table 3 shows that the soil and pasture were even lower in cobalt than those considered above; and a similar increase in the cobalt-content of the pasture could be expected after treatment. The area was not sampled while the lambs were on it, but small samples of the remaining closely grazed herbage, taken early in October, showed contents of 0·13 and 1·59 p.p.m. Co; although these samples cannot, as a result of the very close grazing, be regarded as truly representative of the pasture consumed, or as being comparable with samples from ungrazed areas, the effect of the cobalt dressing in increasing the cobalt-content of the pasture is indicated. As about 8 in. of rain fell during the month following application of the top-dressing, it is unlikely that any of the cobalt, applied as an easily soluble salt, remained to contaminate the herbage.

It is evident, from the soil and herbage analyses and from the striking difference between the two batches of lambs on experiment, that pining in lambs due to cobalt-deficiency can be cured and prevented by top-dressing the herbage with a cobalt-rich fertilizer at the rate of 2 lb. of cobalt chloride per acre. The far-reaching importance of this conclusion is evident, and therefore it is hoped to confirm the above results by a similar experiment on a much larger scale in the near future. In order that conclusions may be drawn on the duration of the beneficial

effects of cobalt manuring and on the relative merits of frequent light or infrequent heavy dressings, further observations are being made.

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ANIMAL INDUSTRIES IN TROPICAL AUSTRALIA[1]

R. B. KELLEY

(C.S.I.R. F. D. McMaster Field Station, Badgery's Creek, N.S.W.)

THE earliest permanent settlements in Australia were confined to the southern and south-eastern littoral; from them pastoral activity expanded rapidly in every direction inland, using imported stock, among which British types were favoured as most of the early migrants came from the British Isles. Indian cattle and buffaloes were introduced at Port Essington (near where Darwin now stands) in 1872, Indian and Cape sheep were among the early flocks depastured near Port Jackson,

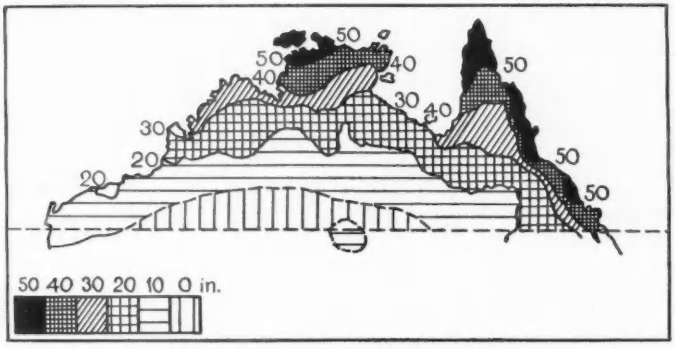

FIG. 1. Mean annual rainfall [2].

but the first introduction of Merino sheep was accidental. Broadly speaking, and regardless of their location in the continent, the flocks and herds of Australia are of European origin and mainly the progeny of stock imported from the British Isles. Thus the tropical belt of Australia is unique in this respect, and the problem of providing ameliorating factors for animal production, in tropical environments where cattle and sheep are depastured all the year round under natural conditions, first requires a knowledge of the climatic and other conditions to which the animals are subjected and the extent to which, economically, they have become adapted to them.

The Australian Tropical Environment for Live Stock

Climate. The climate of tropical Australia has been classified by Trewartha [1] as tropical savannah, low-latitude steppe, and low-latitude desert, with, in addition, a relatively small area of tropical rainforest principally on the east coast. The rainfall conditions are shown in Fig. 1 [2]. Characteristically, the total rainfall of the savannah is less

[1] Condensed version of paper read at the Seventh International Genetical Congress, Edinburgh, August 1939. The original, with additional plates and diagrams, is deposited with the Imperial Bureau of Animal Breeding and Genetics, Edinburgh.

than that of the tropical rain forest, 40–60 in. being more typical of the latter, and is unevenly distributed throughout the year; and because the savannah type usually occupies a transitional belt, there is considerable contrast between the amounts of rainfall on its margins. The type of rainfall at three centres from east to west in the savannah belt of tropical Australia is shown in Fig. 2. The average annual rainfall at these sites

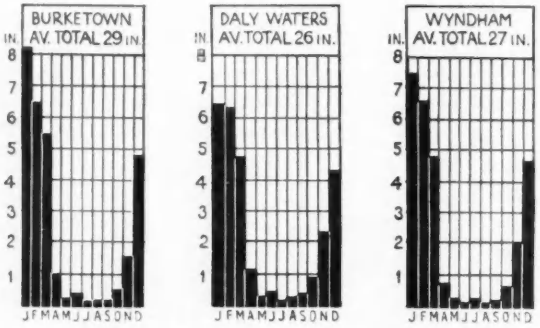

FIG. 2. Annual rainfall showing mean percentage variation from the normal [2].

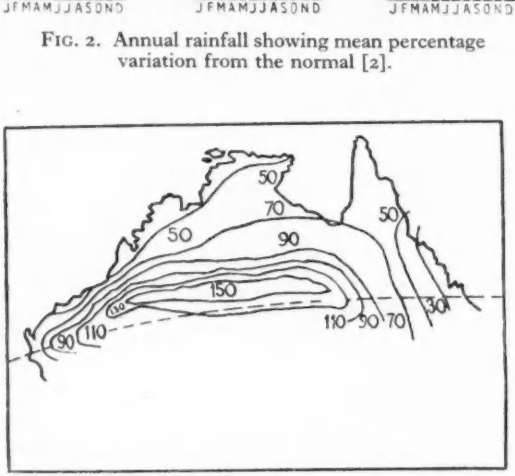

FIG. 3. Steppe region; consecutive days over 90° F. [2].

is, moreover, relatively low. In the steppe regions seasonal temperatures are extreme and annual ranges large, as at Nullagine, Tennant's Creek, and Longreach, where the ranges, from monthly averages, are 58°, 46°, and 55° F. respectively. Further, scorching desiccating heat prevails; at Marble Bar, W.A., 90° or over has been recorded on 151 consecutive days; the numbers of consecutive days during which air-temperature has exceeded 90° are shown in Fig. 3 [2].

Means of annual climatic data for representative points in the steppe and desert belts are given below.

(a) Desert Belt

State	*Station*	*Lat.*	*Long.*	*Alt. (ft.)*	*Mean max. temp.* ° F.	*Mean min. temp.* ° F.	*Mean rel. hum. Sat.* = 100	*Av. rain-fall (mm.)*
Q'ld.	Boulia	22° 55′	139° 38′	478	89·2	61·7	38	1,038
N.T.	Alice Springs	23° 38′	133° 35′	1,901	83·8	55·4	37	1,079
W.A.	Mundiwindi	23° 52′	120° 10′	1,840	87·0	58·8	32	1,019

(b) Steppe Belt

Q'ld.	Longreach	23° 27′	144° 08′	612	88·1	59·4	50	1,653
N.T.	Tennant's Ck.	19° 34′	134° 13′	1,075	89·4	65·3	36	1,472
W.A.	Nullagine	21° 53′	120° 05′	1,265	90·9	61·5	38	1,325

Tropical Australia is thus wholly within the summer-rainfall belt; approximately seven months are without efficient rainfall. Further, annual precipitation is extremely variable, as well as so low on the average that Australia as a whole is classified as the most arid of continents. Instances of unreliability are given in the following records for Onslow, in the low-latitude desert in Western Australia, and Borroloola, in the savannah belt on the south-west shore of the Gulf of Carpentaria:

Onslow:	April 1900	11·00″	May 1900	10·50″	(Mean average annual rainfall for 45 yrs. = 9·06″)
	April 1901	0	May 1901	0·50″	
	(April average	0·9″)	(May average	1·5″)	
Borroloola:	March 1899 .	29·00″	Feb. 1896	21·4″	
	March 1900	0·5″	Feb. 1897	4·7″	
	(March average	6·0″)	(Feb. average	7·4″)	

Apart from the Atherton Tableland, an area of approx. 12,000 sq. miles on the Queensland side (Lat. 17° 23′, Long. 145° 23′) which is about 2,750 ft. above sea-level, there are practically no elevated plateaux, such as occur in the African upland savannah, to modify the conditions of low latitude.

One outstanding feature of tropical Australia's climate is the dryness of the atmosphere. The relative humidity is much lower in summer than in winter over most parts of the continent, although summer is the rainy season. This dry air promotes rapid evaporation and so lowers the physiological temperature. The average wet-bulb readings at Pilbara are some 20° lower than the dry-bulb, and along the tropic, the mean summer wet-bulb temperature is about 70° F., whilst in the arid interior of Australia the mean annual evaporation from a water-surface exceeds 100 in.

Management.—Within tropical Australia, cattle and sheep are managed extensively. Sheep, in groups of 500 and upward, are depastured in large fenced paddocks the boundaries of which are built to exclude the predatory dingo. Only portions of the cattle country are fenced, however,

and many properties in Northern Territory and Western Australia are worked as open runs. In general, both species, but particularly the cattle, are maintained in a semi-wild state in which they are mustered for branding and marketing, whilst the sheep are gathered for lamb marking and shearing. In addition, however, outbreaks of disease among the cattle, or of 'fly strike' among the sheep necessitate further handling.

Water-supplies.—Supplies of water within this belt are derived either from surface-catchments (generally deep natural holes in otherwise dry river-beds, or lagoons in flooded country), from relatively shallow wells, or from deep bores which tap the sub-artesian and artesian water-supplies.

Surface-water is relatively pure but underground supplies are frequently rich in mineral salts. Brünnich [3] reports that many of the well-waters and waters from shallow bores are saline, but water from artesian bores is comparatively free from salt. Among about 180 analyses of bore waters, only 10 contained more than 100 grains of salt per gallon and only 6 of these more than 300. Water containing 600 to 700 grains of salt per gallon caused heavy mortality among sheep after using it for a few months; water containing up to 300 grains of salt per gallon apparently may be used with safety, although many animals will refuse to drink water with this amount. Alkali carbonates are frequently found in artesian-bore waters. Among the 180 samples already referred to, 109 contained up to 20 grains of sodium carbonate and the remainder contained more than 20 grains per gallon. The maximum amount of salt recorded in bore-water is 200 grains, and the maximum amount of sodium carbonate is 576 grains per gallon.

In view of the periodic and relatively low rainfall characteristic of tropical Australia, too much emphasis cannot be placed upon the very great value of these subterranean water-supplies.

Below several areas, but particularly under a large area of the eastern portion of tropical Australia, is a series of permeable sediments at various depths to 5,000 ft. below the surface. These underground waters, when tapped, gush to the surface in flows up to several millions of gallons daily. They are conveyed for miles in small channels known as bore-drains. Upon one well-improved cattle property, 2,000 sq.m. in extent, there are 200 miles of these drains, so that at no point can a beast be further than two miles from water. The extent of the Artesian Basins is shown in Fig. 4.

Diseases.—Chief of the epizootic diseases of cattle is pleuro-pneumonia, which was introduced into Victoria in 1858 and, although under control in the southern states, is now general throughout the tropical belt. Buffalo fly (*Lyperosia exigua*) was introduced into the Northern Territory with some cattle from Timor in 1824 and has now extended into Queensland. Cattle ticks (*Boopholis australis*) were introduced from Batavia in 1872 by cattle brought to Darwin. They reached Queensland by 1894 and have now spread all over that portion in which the rainfall is suitable for their propagation. Thus they occur particularly along the coastal fringes.

The soils in many parts have been shown to be low in phosphorus and upon these osteomalacia appears in young growing stock, and particularly in females of this kind when suckling their young.

Soil and vegetation.—The soil types and vegetation-associations which characterize the belt are described by Prescott [4].

It is evident from the foregoing that the Australian tropical environment affords no suggestion that either British breeds of cattle or wool-

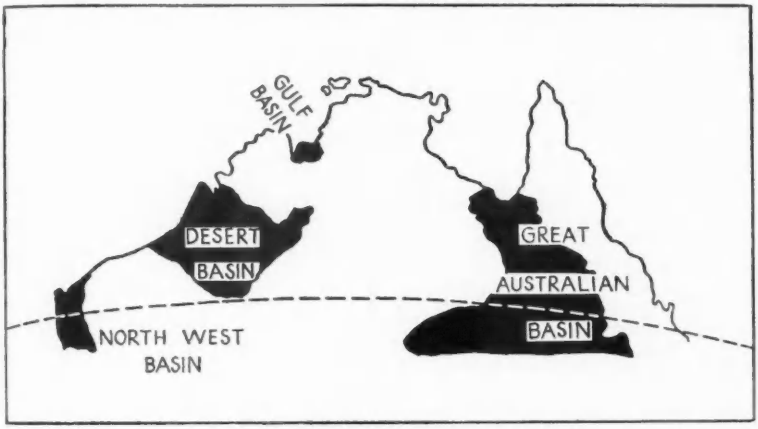

FIG. 4. Artesian basins of northern Australia (A. V. G. James, 1927).

bearing sheep could become established in it, yet these animals have been maintained, with some degree of success, at least upon the savannah and steppe country for many years.

The Animals and their Earning Power

The use to which much of the country has been put is shown in Fig. 5, with the estimated carrying-capacity in terms of cattle per square mile. In the sheep country between 5 and 12 acres are appropriated per animal, except on the 'downs', where approximately 4 acres are expected to maintain 1 sheep all the year round. Good cattle country will maintain 15–20 head per square mile.

Sheep.—All the sheep are Australian Merinos. An authentic breed-history during the early years of settlement has not been traced, but it can be established that in the Merino stud-flocks the imported Saxon and other strains were isolated. The process of evolving the fine-wooled sheep has been continuous for about 150 years, and has been characterized by the introduction of relatively few Merino sheep, the early cessation of importation, the continued isolation of at least three, and probably four, major groups and the subsequent dissemination of the resultant types. Two of the major groups, the South Australian and the Peppin, with histories established, respectively, from 1843 and 1861,

have provided practically all the progenitors of the 10,189,200 Merinos within the tropics (approximately 10 per cent. of all sheep in Australia), which under normal conditions produce an annual wool clip valued approximately at £A.4,750,000. On the eastern side (Fig. 5) there are 8,553,000 sheep (about 42 per cent. of all the sheep in Queensland), whilst the western group numbers 1,625,000, of which 249,000 are in the Marble Bar district. There are only 11,200 sheep in the Northern Territory.

Among those in Queensland, the percentage lambing over a number

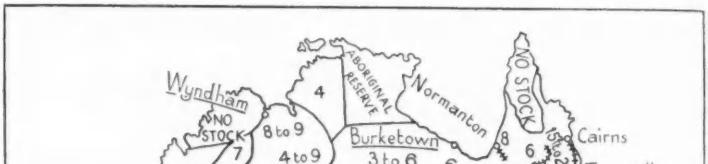

FIG. 5. Use of country and estimated cattle per square mile; meat works and railways.

of years moves through a range of 21 per cent. from a minimum of 40 per cent. It is not yet clear how much of this apparently reduced fertility is due to infantile mortality. There are other possible causes associated with mating times and with testicular changes during periods of intense heat.

Climatic factors, and particularly the short summer growing-season, make either mating or lambing a hazardous procedure, and a five-months period of gestation associates indifferently with an annual period of seven months without vegetable growth. However, there are indications that the Merino ewe has an annual breeding season [5], and this is being investigated within the tropics in an endeavour better to synchronize mating and lambing with climatic conditions.

In practice, many of the sections shown as carrying sheep (Fig. 5) are stocked with wethers only, and regarded as wool-growing country, as distinct from breeding areas. There are, however, marginal lands in which breeding is practised, and it is in them that the problems of reduced fertility are most evident.

The annual losses among all sheep in Queensland vary widely with a maximum during drought of approximately 21 per cent. of the total for the State to 10 per cent. as the minimum for a ten-year period.

Climatic factors, reflected in the available food-supply, have a greater

effect upon the death-rate than maintenance *per se*. In 1935, when the loss due to drought conditions over the whole state of Queensland was 3,327,029, being 74 per cent. of all causes, a statistical group, wholly within the tropics, had 77 per cent. of all loss from this cause, whereas one below the Tropic had 76 per cent. Both, however, were in the summer-rainfall belt.

Recoveries after drought are almost phenomenal. In 1891 Queensland had some 22 million sheep; after several lean years and the drought of 1901–2, there were about 7 millions, but in 1915, only 14 years later, their number was approximately 24 millions.

Beef-cattle.—There are approximately 4,200,000 head of cattle within the Australian tropics, about 30 per cent. of the total on the Continent. Excepting about 62,000, all are beef-cattle of various British breeds and their crosses; among approx. 3 millions in tropical Queensland, 14 per cent. are Shorthorns, 3 per cent. Herefords, with Red Polls, Devons, and Aberdeen Angus accounting for, roughly, 0·3 per cent., 0·1 per cent., and 0·05 per cent. respectively. Observation suggests that Shorthorns also predominate among those of unspecified breeding.

Herefords are relatively strong in the coastal and near-coastal belt in the south-eastern corner of Queensland, from Rockhampton to Mackay: there is a further group in the hill country centrally situated, approximately west from the Atherton Tableland. Red Polls play a leading part in the breeding-policy of one pastoral company with extensive holdings adjacent to and south of the Gulf of Carpentaria; and inland from Townsville, Devons are much used for crossing with Shorthorn cows. Most of the Aberdeen Angus are in studs, but number only about 11,000 (0·2 per cent.) in the whole state of Queensland.

Shorthorns are preferred for two main reasons: being docile, they are fairly easy to handle under extensive conditions. Secondly, until quite lately, the export trade was based upon freezing rather than chilling processes and thus the product met with no strong condemnation overseas if it exceeded, in carcass-weight, the optimum requirements for the higher grade of trade. Appreciating this, pastoralists set out to grow cattle which reached heavy weights when sold, even if to do so they were held until five or six years of age. There were also other factors.

As sheep are in general more profitable than cattle, the latter industry has been forced slowly to retire to regions least favoured with regard to climate, vegetation associations, and transport facilities. In these, weaned calves often secure insufficient sustenance during their first long winter 'dry season'. This results in a 'store' period of skeletal growth. Throughout subsequent wet and dry seasons, flesh is built up and lost until the animal reaches maturity. Then, as the result of its last 'wet season', with no growth-requirement, it fattens and is sold.

Under these conditons, cattle with smaller frames than Shorthorns would give a relatively low gross return. Further, there are few railways through the cattle country (Fig. 5), and very often fat stock have to walk hundreds of miles to a trucking-point; the big mature animal stands the journey better than any other.

Devon bulls are used for crossing with large-framed Shorthorn cows,

a policy which antedated the introduction of chilling, and results in a carcass of suitable weight for chilling. Further, by decreasing the size of the cross-bred, it reduced the scale and period of growth, so that well-fleshed animals could be marketed earlier. These bullocks from the north-east, and Herefords occurring in the south-eastern coastal section, even during the freezing period, were favourably criticized in this country and in England. Now that chilling is established, they are eagerly sought by exporters. The essential problem for cattle-growers, however, is to produce such bullocks over the inland and least-favoured areas.

Large slaughtering plants within the tropics are located at Wyndham, Townsville, Bowen, and Rockhampton. In addition, a small plant has

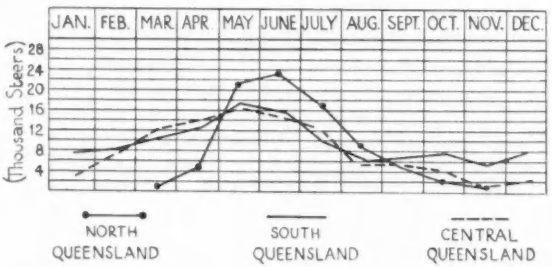

FIG. 6. Monthly killings—North, Central, and Southern Queensland.

started at Burketown. These points, with their associated railway systems, where these exist, are shown within the cattle country in Fig. 5.

The rainfall over the tropical area controls the fattening period and so also that of killing. The accompanying figure (Fig. 6) shows that in North Queensland the killing season is from April until July, with May and June as the busiest months.

In the 'frozen' trade, regularity in exports can be secured to some extent by storing the product for lengthy periods. It is thus adapted to continuous export, notwithstanding heavy seasonal killings. Chilled beef, however, must be dispatched immediately after slaughter and cannot be stored after removal from ships' chambers. The change-over from freezing to chilling, however, discloses the problem of continuity of supply. The peak of production (Fig. 6) must be flattened, not only to secure regularity, but because this slaughter-peak represents summer sales in England in a period of reduced demand for meat.

In the curves for monthly slaughterings from Central and Southern Queensland (Fig. 6), it will be seen that the seasonal peak is progressively less pronounced in lower latitudes. This is a point now receiving attention from producers. There is an increasing tendency for cattle, as far west as the central portions of the Northern Territory, to be sent overland into Central and South Queensland, where the growing-season for plants is longer. Unfortunately, however, there is no such fattening

area as that found in the Argentine. Further, dairying and sheep-raising being more remunerative, the use of high-quality land for finishing off beef-cattle is not commercially sound.

The southern States of the Commonwealth annually absorb ever larger quantities of northern beef, either on the hoof, as in Western Australia, or dressed and chilled, as in the eastern States. This factor, together with the impetus given to the export trade by the introduction of the chilling process, has markedly improved prices at northern killing-points. Within a few years beef has risen in value at the Townsville works from 14*s.* to 25*s.* per 100 lb. for first-quality stock.

The method of sale in the north is that herds of cattle are driven to a trucking-point and railed to the meat works or driven direct to them. The dates for their arrival are fixed by the meat works' executives so that their holding-yards will not be over-taxed. Slaughter is usually carried out on the American chain system and payment is by quality. Government graders assess this, and all meat for export is killed under the supervision of veterinary officers of the Department of Commerce.

Vital statistics for tropical cattle are unprocurable from official records, and even upon properties the available data have been found insufficient to assess the position accurately. Generally, 'book figures' are carried nominally to represent the number of cattle upon a property. From these an annual deduction of 5 per cent. is made for 'mortality'. Actual average mortality, however, upon one property between 1928 and 1932 was found to be equal to 9 per cent. of males and 11 per cent. of females. Cattle sold are also periodically deducted from the nominal total. After every branding the tally of calves branded is added to the 'book figures'. This addition, in normal years, is expected to equal 25 per cent. of the total herd. Upon one typical property near the Gulf of Carpentaria, over a 19-year period, these 'book figures' showed seven years with totals lower than the previous year.

The annual draft for sale, principally of bullocks, is expected to be 10 per cent. of the herd. In coastal districts of the south-eastern corner, a draft of fat bullocks is expected to have approximately 25 per cent. of three-year-olds with the remainder four-year-olds and upwards.

Generally the bulls remain in the breeding herds all the year round, and there are two principal brandings. On the best-managed properties there are 'weaner' paddocks, 'bullock' paddocks, and 'breeding' paddocks, the cattle being 'worked' as these names indicate. On the 'open runs', where all sexes and ages run together, there is an annual muster at which calves are branded and sales stock drafted off.

Although the foregoing figures are inadequate, they form a fitting introduction to the following statement with regard to Queensland by the Chairman of the Meat Board at a recent scientific congress in Brisbane: 'The production of beef is approximately 3 lb. weight per acre per annum and the average would be lower if only the industry in tropical Australia was considered.'

There are no figures available to show the annual gross return from beef-cattle within the Australian tropics. For comparison with the

revenue from sheep, however, an estimate has been prepared, based upon 10 per cent. of sales stock dressing 700 lb. and selling at £1 per 100 lb. This estimate approximates £3,000,000 annually.

Dairy cattle.—There is no evidence to suggest that any number of dairy cattle are maintained in the north-western portion of Western Australia or in the Northern Territory. In tropical Queensland, however, there are approximately 62,000. Some of these are associated with the larger urban communities for which they provide fresh milk, but most of them are on the Atherton Tableland (56 per cent.) or along the eastern coast (30 per cent.). As with beef-cattle, the official figures show many fewer pure-breds than cross-breds. Among the pure-breds however, milking Shorthorns (Illawarras) and Jerseys predominate (98 per cent.). Further, milking Shorthorns (Illawarras) exceed the Jerseys by 26 per cent. (62 and 36 per cent. respectively).

If that at Rockhampton, upon the tropic, is included, there are nine butter factories but no cheese factories along the coast or upon the tableland. Annually these manufacture butter to the estimated value of £400,000, more than half of which is produced upon the Atherton Tableland. This large proportion is not due alone to numerical superiority, but also to higher individual production. The average milk yield per head on the tableland is 64 per cent. greater than that for all other cows within the tropics.

Pigs and other animals.—In northern Queensland there are approximately 23,400 domestic pigs. The favoured breeds are the Berkshire and Tamworth, as it is thought, in some cases correctly, that white-skinned pigs sunburn and scald in the tropics, although some strains of Large York are no more affected in this respect than other pigs. Annual killings reach 24,000, chiefly for fresh or salt pork. With pork at 6*d.* and bacon at 1*s.*, the estimated aggregate annual value of these is £A.67,000. Approximately 66 per cent. of all the bacon is produced at one curing plant, supplied from the Atherton Tableland, Rockhampton producing nearly all the remainder.

Not shown in official figures are the domestic pigs living in a wild state along the rivers and in swamps all through more favoured portions of the tropical north; most of them are black, some have red spots, and are generally reminiscent of inferior Berkshire × Tamworth crosses, although among whole blacks, the body is short, the snout long, and appearance similar to the old Chinese pig.

Other animals are of little economic importance. Buffaloes from the East Indies have thrived in a wild state in the wet coastal districts of the Northern Territory; their hides return about £2,500 annually. Common goats number 80,000 in Queensland, 10,000 in Western Australia, and 17,000 in the Northern Territory; camels (now replaced for freight purposes by motor transport) in these States number 300, 2,000, and 310, respectively. There are about 1,000 Angora goats in Queensland and 900 in Western Australia. Donkeys and mules, used to some extent for draught and pack work, number 30 and 1,000, respectively, in the State of Queensland, 1,500 and 530 in the Northern Territory, and 7,500 and 1,200 in the whole of Western Australia.

The foregoing assessments estimate the annual value of animal products from tropical Australia at £A.8,250,000 approx. The area of the territory is 1,149,320 sq. m.: thus the annual gross return from animal industries is about £7 per sq. m., or 2½*d.* per acre.

Discussion

Apart from providing watering facilities, very little has been done to improve the requirements for live stock, as compared with those available when the land was first occupied. (The exception is the process of 'ring barking', by which forest timber is killed and growth of grass promoted in the south-eastern coastal country.) On the contrary, by stocking the native flora up to and in many cases beyond its maximum carrying capacity, the available food-supply, over large areas, has been seriously affected both in quantity and quality.

There is ample evidence to show that even potentially rich soils and their vegetation associations cannot indefinitely withstand heavy grazing. No return to compensate for the constant withdrawal of the mineral and other requirements of the stock has ever been made in tropical Australia. When an area is subjected to periodic dry times and recurrent droughts, the potential soil fertility may be conserved during the resting periods, but if during these large numbers of live stock are held upon restricted areas, then regeneration of the perennial vegetation is impossible. Over wide areas this has taken place and, upon second-generation and longer established properties, the present number of live stock is commonly only half that carried upon the same area during the previous generation. The degree of exploitation has been similar for the underground-water supply. So many artesian bores have ceased to flow or become reduced in output that a special Government Department has been formed recently to conserve the waters of the basin and control their use. Thus the period of occupation has considerably reduced many of the country's natural advantages.

Within the Research Departments of Australia we are now working upon the problems of drought feeding, 'fly strike', and reduced fertility in sheep; upon exotic grasses and their use in the high-rainfall belt as fattening grounds for cattle; upon such diseases as piroplasmosis and pleuro-pneumonia of cattle, and upon the carriage at sea of beef in a chilled state during relatively long voyages; all of which are problems related to animal production with specific application to our tropical conditions.

It is probable, however, that insufficient attention is being given to the underlying ecological problems. Notwithstanding the annual revenue stated to be derived from European breeds of animals in tropical Australia, there is no evidence to suggest that these can be maintained at their original high level under such conditions. On the contrary, it is well established that an animal is the product of its heredity and its environment.

Unfortunately, except with regard to camels, buffaloes, and Zebu cattle, no direct observations as to the truth of this generalization are

possible in Australia because, as has been stated, here all animals other than these are of European origin.

The earliest history of existing British breeds is one of isolation, inbreeding, and specialization in a marine west-coast climate. It is peculiar in that it is common only to portions of Europe and the State of Victoria (Australia) and the whole of Tasmania and New Zealand [1]. For geographical reasons the animals most likely to suit the climate of tropical Australia would be those for which Epstein [6] has traced the genealogy, viz. Zebu cattle.

European breeds of cattle have been introduced to West Africa, Kenya, Rhodesia, and the Union of South Africa. Buchanan Smith [7] has reported that the venture was without success in West Africa. In Tanganyika [8] a policy of degrading is being advocated when the 'improved' stock has reached 75 per cent. British. In Kenya, altitude affords some relief. In South Africa [9] cattle graded up from native cattle with imported breeds of European origin have been unable to withstand the local conditions and are now being crossed with Africanders.

In Asia, various breeds of dairy cattle have been taken to India. There they have failed to withstand the climate, and an endeavour is being made either to select high-producing strains of local cattle or to establish, by crossing with native cattle, a type with some admixture of European 'blood'.

In the Philippine Islands, British-bred beef cattle also have failed to withstand the climate and a cross of Hereford, with native cattle and Zebus is being established. In Trinidad, for milk production, reliance is being transferred from European stock to crosses between these and Zebu cattle [10].

In the southern States of the U.S.A., hybridization of Zebus and British cattle is carried out very extensively and is giving better returns than those derived from British cattle.

With regard to wool-growing sheep, the evidence is neither so comprehensive nor so clear. Generally, sheep of this kind are not found anywhere within the tropics except in Australia.

Throughout that part of Africa which is south and east of the Belgian Congo, only the Union of South Africa and the small native protectorates (Basutoland and Swaziland) are important wool producers: 'The others are, in the main, too warm for wooled sheep' [11]. Apparently the available food-supply causes stratification so that Merino sheep occupy the best of the dry country, non-wooled Blackhead Persians come next, and where grazing conditions are too adverse for either type of sheep, common goats, used for skins, can exist.

Such observations lend no support to the continued maintenance of British cattle or wooled sheep within the Australian tropics.

More direct evidence from the Zebu hybridization experiments of the Council for Scientific and Industrial Research has shown that the Zebus and their crosses do remarkably well in tropical Australia. Kelley [12] reports that the imported animals, nineteen in all, have remained in excellent condition throughout five years of station life in

the Australian tropics. Five pure-bred males and five pure-bred females have been reared. Matings resulting in four males and three females have been made between the imported three-eighths Santa Gertrudis cross-bred bull and some of the imported females. Hybrid progeny by the imported bulls greatly outnumber all other kinds. Accurate figures are unprocurable because only branded calves are counted, but the approximate total is 1,193, comprising 26 three-quarter-breds, 630 half-breds, and 548 quarter-breds. Of the hybrids, 333 are bulls of various ages, 261 are steers, while the remaining 599 are females. The pure-breds are repellant to cattle ticks, have a high resistance to infection with *Piroplasma bigemina*, and are more tolerant of heat than British-bred animals. It has also been observed that they transmit these peculiarities to their cross-bred progeny. Further, it is apparent that the cross-bred's degree of characterization exists in direct proportion to the percentage of Zebu 'blood'. Their beef has been shown to be suited to the chilling and export trade by carcasses from cattle with up to 50 per cent. of Zebu 'blood' satisfying critical examination. The imported Zebus and their progeny have been exposed to extreme drought conditions. Upon one such occasion the northern divisions of Queensland, in which these observations are being carried out, lost 63 per cent. of their British-bred cattle. There were no losses among the experimental groups although no supplementary feeding was practised.

These observations indicate that, in many respects, Zebu hybrids would be excellent animals with which to stock northern holdings. However, with regard to the timidity and liveliness of these animals, caution is necessary before such a recommendation could be made. The observations must proceed until it is shown what percentage of Zebu blood combines the advantages of the tropical type with the docility of the British breeds.

The question is one of agricultural economics rather than of ecology, and is allied to those indicated with regard to maintenance of non-wooled sheep and goats in other countries with a climate similar to Northern Australia, but where large native populations provide cheap labour and use cheap food. The first ensures that the animals and particularly the cattle are constantly handled and so quietened, while the second provides a ready market for mutton and other meats unsuited for the most discriminating world's market.

In Australia, however, live stock must be handled economically to be sold competitively upon overseas markets. Thus, in a country of high wages, for station cattle to be given adequate handling to reduce their nervousness, the added cost must be associated with increased production or similar gain. This point is now being investigated in respect to the hybrids.

Problems of animal production within the Australian tropics, therefore, must be approached biologically and commercially. Upon ecological grounds sufficient justification has been presented almost to warrant entire reconstruction of our animal industries. Nevertheless, for many years they have returned a very appreciable gross income and so justified

their maintenance. Admittedly the variable rainfall introduces a hazardous risk, but this can be insured against by establishing financial reserves in seasons of plenty. Organizations rather than individuals are more likely to have sufficient strength and foresight to do this. Nevertheless, therein alone lies a successful future for animal industries as now conducted within tropical Australia.

The study of ecological problems must be accompanied by one which reviews the soundest business methods and establishes the amount of reserve capital adequate to cover the disclosed risk of operating in such a territory. Further, until these studies are made, animal industries within the Australian tropics should be regarded as being in formative rather than in established states, and as being to some extent fortuitous.

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THE ECONOMIC EXPLOITATION OF RICE GRASS

JAMES BRYCE

WITH PLATES 8 and 9

PUBLIC interest in Britain in Rice or Cord Grass (*Spartina Townsendii*) may be said to have been first aroused during the war of 1914–18. In those years the plant was systematically cut by organized schoolboy labour and prepared for paper-making. The termination of that war brought these well-intentioned but shortlived efforts to a premature end.

During the five years which followed, interest centred round the work and writings of Prof. F. W. Oliver on the botanical characters, habitat, and economic possibilities of Rice Grass, with the result that knowledge of the plant was carried wider afield to the Dominions, Colonies, and foreign countries. Of these lands the one most quickly and effectively to apply the lessons which had been learnt was Holland. Since 1925 the Dutch have taken the lead in finding ways of fully using the powers of Rice Grass as an aid in land-reclamation. They have given Rice Grass a definite place in their technique. The results have been spectacular.

From 1925 onwards to 1938 the main experimental work in England was done in Essex, and was directed primarily towards discovering the range and limitations and means of artificial propagation of the grass. In a minor degree the feeding-value for stock was explored more exactly than hitherto. Since 1938 further investigations have unavoidably been held up. It is, however, now possible to specify with a reasonable degree of precision the situations colonizable by Rice Grass, and also to indicate from the reports of experimenters overseas its probable geographical range. That having been done, it still remains to elucidate the more important limiting factors of a local kind within the normal range and methods of overcoming them. Further work is also desirable in examining all its potentialities as a fodder plant.

The most important of these limiting factors almost certainly is the action of eddying, swirling, or turbulent water during submersion. Precisely what effect such disturbances have on the living organs of the plant, or alternatively what degree of mobility of its immediate environment Rice Grass will stand, has still to be ascertained.

The potentially colonizable region of Rice Grass is to be found on tidal mud-flats between the levels of about 1 ft. and 6 ft. below average spring-tide high-water mark. Within this region optimum growth occurs between 1 ft. and $3\frac{1}{2}$ ft. below spring-tide high-water mark. Depth seems to be more significant than time of immersion. Six hours' continuous immersion in shallow water is common. The latter characteristic is clearly one of great value in land-reclamation.

At all levels within the colonizable region areas barren to Spartina may occur. Perhaps the most striking of these are the depressed 'pans' which form so regular a feature of the Essex saltings and in which the tide gently circulates in conformation with the banks. Similar action of

the tide is promoted on a larger scale on lower sites at angles of sea-walls and in parts of enclosed harbours. A general survey of the natural Spartina fields on the south coast of England in 1934 revealed the existence of such barren areas in Christchurch harbour, and even in Poole harbour, in which there could not have been lack of seeds or living fragments of plants suitable for propagation. (This survey was made primarily to compare and contrast the conditions in the natural Spartina fields on the south coast with the experimental ones in the Essex estuaries. In the main the result showed that on the south coast the range of Rice Grass in regard to depth was of necessity restricted and at the same time over a large area the period of immersion was more prolonged. Consequently, it has been possible in Essex to test growth-reactions down to relatively low levels.)

The Dutch engineers, who had also experienced failures with Spartina, have since 1935 developed a method not only of rendering many barren areas fertile to the grass, but also of promoting its growth in the more favourable situations. The kernel of the matter is simple and may be summarized quite shortly in terms familiar to those with a knowledge of clay farming in Essex. It is to grow the plant on the 'stetch' or ridge and not on the flat. A visit by the writer to Holland in 1938 in company with Prof. F. W. Oliver showed what was being achieved by the new method, and how the method itself was no more than a development of past experience in land-reclamation over a period of a few hundred years.

It is, of course, well known that the Dutch are traditionally intensely interested in the reclamation of tidal lands by the accretion and holding of silt brought to them by continental rivers. The problem has been the arrestment of the silt carried in their estuarial waters, and from time immemorial they have recognized the dual need of preventing the scouring action of tidal currents and of slowing down of the ebb and flow to give the clay particles time and opportunity to settle. They have to the present day endeavoured to achieve their objectives by the skilful disposition of more or less elaborate systems of dams.

In lessening severe scour, dams of various types rising to a few feet above the general level are employed, whereas for regularizing the currents in shallow waters over extensive areas and contributing something to their impediment, the surface is ridged in a definite pattern by digging shallow ditches or drains and throwing the material up on either side. These ditches communicate with larger ones so that the area under treatment has a common surface-drainage system. In elaborating these works the Dutch acknowledge their debt to the Germans of the North Sea coast of Schleswig-Holstein, where in the first instance the surface draining of 'saltings' was practised in order to encourage the extension of the coastal belt of vegetation for grazing purposes. Later, by continuing them outwards and improving them, tidal scour was lessened. Since 1900 low brushwood dams set in a regular pattern over wide mud-flats have been introduced. By such means the Germans were successful in substantially ameliorating coast erosion, which on this littoral had become a major problem.

Since 1935 the Dutch have combined the scheme of low narrow ridge-like dams with the brushwood type, and have in addition superimposed Spartina on the surface-ridges. In this way they have been able to cultivate this grass in new areas otherwise difficult or impossible, by reducing the eddying limiting factor of the tides, and have thus successfully extended this powerful agent in slackening tidal flow and accelerating silt-accretion and fixation to a wider field.

The photographic illustration (Fig. 1, Plate 8) gives an eye-impression of the layout in a typical area. It is of the Lauwers Zee in north Holland and was taken in September 1938. The main system of brushwood dams arranged in 400-metre rectangles by means of which the tidal waters are compartmented is shown. These dams are made of two rows of wooden stakes standing from 0·85 to 1·5 metres above the surface with pine or willow brushwood packed between them. A revetment of Spartina or *Atriplex littorale* is sometimes added to the base to prevent undercutting. Within the squares the surface is ridged and drains dug, both flanking the ridges or 'stetches' and at right angles to them. The deeper and wider transverse ditches are placed about 80 metres apart. Spartina is then planted in blocks beginning inshore, two rows of plants being set on each ridge.

In Holland cattle and sheep are not allowed to graze Spartina, since its value in reclamation is placed far above its feeding-value. At the time of writing in England the roles are reversed. The natural Spartina fields of England could if required yield an annual weight of 40,000 tons of dried fodder of good quality for most kinds of stock.

The last summary of attempts to exploit Rice Grass in the Dominions, Colonies, and foreign countries other than Holland, was published in 1936 in the Kew Bulletin of Miscellaneous Information. Since then further attempts have been made, by using rooted cuttings, at Lagos, Nigeria (1938); Port Hedland, Western Australia (1936); Bengal, India (1937); Kingston, Jamaica (1938); and by seeds at Hong Kong (1937). No information of the ultimate results is available, although at Lagos and Jamaica the early stages of growth were reported to be promising.

The site at Lagos was described as consisting of large areas of tidal swamps to the south of the Five Cowie Creek Bridge for which drainage and reclamation proposals had been put up, firstly as a sanitary measure and eventually to provide new building ground. In view of the latitude approximating to that of British Guiana, where *Spartina Townsendii* had failed to establish itself and to compete with the native *Spartina brasiliensis*, a recommendation was made that the latter might also be tested at Lagos.

At Port Hedland, Western Australia, Rice Grass was wanted to reclaim salt marshes. 'They are damp the whole year round, but during the rainy season from January until March or April they are usually under water to a depth ranging from 6 to 12 inches. This water immediately after rain is quite fresh, but in a few days is decidedly salty and then quickly becomes quite salt. However, there is no deposit of salt visibly left on the surface of the marsh when the water dries off. Here and there in odd places a type of samphire comes up which is a bulbous weed

containing a lot of brackish water. I have been experimenting for years with different types of grasses, and have got several which have been imported from overseas and have suited and thrived on some types of our country. One importation from South Africa has increased our carrying capacity from 20,000 sheep to very nearly 30,000, and it is still gaining ground and improving pasture. Should Rice Grass take readily to our marsh country in the course of time it could quite easily mean carrying 2,000 or more sheep in what is now pure marsh with no vegetation' (from F. F. Thomson, Pardoo).

It is not clear whether the salt marshes at Port Hedland are connected with the sea. The inference would seem to be that they are not directly joined. In that event Mr. Thomson's problem appears to resemble in some respects that of Mr. Campbell at Corobimilla, N.S.W., previously described (Kew Bulletin). At Corobimilla, Rice Grass was introduced with the expectation of its replacing the natural herbage which was being destroyed by brackish water from artesian wells. The expectation was being fulfilled in 1930. An illustration not hitherto published of the first plantation as it was in 1933 is shown in Fig. 2 (Plate 9).

In Bengal the plants were sent to the Department of Irrigation for test on the banks of the Ganges below Calcutta in reclaiming peasant lands that were lost owing to drainage difficulties.

At Kingston, Jamaica, the site was a 'swamp quite cut off from the sea and so not tidal at all. It has a habit of drying out leaving a comparatively small pool of water in the dry season and extending to a sheet of water in the wet season. Since we planted Spartina nearly a fortnight ago, the water has dropped about 6 inches although the rains are approaching. We put the grass in varying depths of water, the shallowest of which is almost completely exposed now. Most of them seem to have taken root and one or two are shooting quite well. There is a local grass growing round the marsh and extending into the water farther than where the Spartina is planted. I understand that it is Crab Grass (*Paspalum conjugatum*), but though it seems to spread fairly quickly it does not seem to meadow well; the tufts are rather sparse and far apart' (Miss Joan Schofield, Oct. 1938).

From Hong Kong there was no indication of the character of the situations for which the grass was intended.

The data now available, and in particular the valuable experiments and observations of E. B. Martyn in British Guiana, indicate that the geographical limits of Rice Grass (*Spartina Townsendii*) are probably to be found on the one hand within the sub-tropical regions about the 20th degree of latitude and on the other in the neighbourhood of the 56th degree north, and the 52nd degree south latitude. Within the tropics proper, *Spartina brasiliensis* seems to be capable of accomplishing what *Spartina Townsendii* can do outside them in the way of coast protection, reclamation of saline lands, and as a fodder plant.

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FIG. 1. Lauwers Zee, Sept. 1938. Rice grass of various ages in foreground

FIG. 2. Rice grass at Corobimilla, New South Wales, in 1933

FARM PROBLEMS OF WESTERN EUROPE

P. LAMARTINE YATES

THE following paper attempts to describe very briefly some characteristic developments of continental farming. Many and various are the paths by which a prosperous agriculture has been sought, but by confining ourselves to the experience of a few near-by countries, where climate and farming practice differ not too markedly from ours in Britain, we may be able to single out certain factors which have had a dominant influence in agricultural progress. No attempt will be made to deal with developments since the outbreak of war; in all that follows, it is the situation *ending in September* 1939 which is described.

France

The French are proud of their peasants. They have always considered themselves a peasant nation. The land has been the source and fountain-head of all that is best in French culture, and rural life has provided the mortar of stability in the nation's growth. Not unnaturally a cardinal principle of policy has always been the preservation of the peasants; on no account must their welfare be subordinated to the interests of the commercial classes.

But the State had also another purpose. It was determined to secure the highest possible degree of self-sufficiency in food supplies. In the seventies and eighties of last century, France was still Britain's enemy, and Britain controlled the seas; moreover, the Germans were starting to build a navy; so that self-sufficiency was considered an objective of some importance.

To achieve these two aims of peasant welfare and self-sufficiency tariffs were introduced in 1885. A duty of 1*s.* 2½*d.* per cwt. was imposed on wheat, and of 7½*d.* per cwt. on rye, oats, and barley. The wheat duty was subsequently increased to 2*s.* 10½*d.* and that on other cereals to 1*s.* 2½*d.* per cwt. At the same period, duties were imposed on meat, butter, and eggs. Thenceforward, for forty years, the tariff position remained almost unchanged, except for a brief waiving of duties during 1914–18. But after the World War, as the French franc fell in value, the tariff schedule, although frequently revised, came to provide less and less protection,[1] until, in 1931, France felt compelled to adopt a far-reaching system of quotas, so as to limit the actual *quantity* of goods allowed in. These quota arrangements she retained with little change until 1939, and they applied to practically every important foodstuff.

Certainly the policy of agricultural protectionism achieved one of its objects in that France has maintained since the eighties a greater degree of self-sufficiency than any other western European country. Her imports consist only of tropical products, plus a little wheat and wine from her own Algeria. She produces 90 per cent. of what she eats and in these days of political insecurity that is something well worth

[1] See M. L. Prault, *Protectionnisme douanier et commerce extérieur français*. Amiens, Imprimerie Nouvelle, 1935.

having. But, on the other hand, she thereby relinquished all opportunity of developing her exports of agricultural produce, of becoming perhaps a second Denmark. Those who are old enough to look back fifty years may recollect how the exports from France of wine, fruit, vegetables, butter, and cheese were steadily increasing, the chief market being Britain. French soils were rich, the French climate excellent, the transport to London easy; everything pointed to the development of a big food-exporting industry. But protectionism made France into a high-cost producer and separated her prices more and more from the world level, so that she found it increasingly difficult to compete in outside markets. Instead of expanding, her exports dwindled; the only remaining trade is in wine and certain 'specialities'.

It can be argued with some force, at least from a political point of view, that self-sufficiency is better than an export trade, and that the sacrifice may have been worth while especially if, at the same time, farming prospered and the peasantry was preserved. But unfortunately the second objective of protectionist policy has by no means been attained. The rural exodus was not checked. On the contrary the number of males engaged in French agriculture has fallen by nearly two millions in the last fifty years, or by 0·7 per cent. per annum, compared with 0·35 per cent. in Germany and 0·3 per cent. in Britain over the same period.[1]

Neither is the standard of life particularly good for those remaining behind. One might imagine that, with wheat prices 40 per cent. higher than in Britain for the last generation (and wheat is far more truly the staple crop of France than it is here), the producers would enjoy a fair return on their labour. Yet the facts are that agricultural labourers in France were earning just before the present war no more than 20–28*s.* per week, according to district, and the vast bulk of the peasant cultivators more or less the same sum. Even in France this does not represent riches. Moreover, housing standards remain incredibly low, whilst the general standard of health and the infant mortality rate are less favourable than in the towns.

In respect, too, of farming technique, France has progressed less rapidly than her neighbours. For example, the following table sets out wheat yields per acre in five countries:[2]

	Bushels per acre		*Increase per cent.*
	1881–5	*1933–7*	
France . .	18	24	33
Germany . .	22	32	45
Belgium . .	26	39	50
Netherlands .	26	46	77
Denmark . .	33	47	42

[1] Calculated by taking the percentage decline between the Census nearest to the period 1880–90 and that nearest to 1930 and dividing that percentage by the number of years between the two Censuses. For instance, the number of males engaged in farming in Germany declined by 17·7 per cent. in 51 years, equivalent to 0·35 per cent. per annum.

[2] From *Food Production in Western Europe*, by P. Lamartine Yates. Longmans Green, 1940, whence also subsequent tables.

Thus in France the increase has been only 33 per cent., in the Netherlands 77 per cent. A similar story could be told of milk yields, if enough figures were available for the earlier period. In any case, the following comparison with Denmark is interesting:

	Gallons per cow per annum	
	*Denmark**	*France†*
1860 .	213	?
1930 .	700	380

* Danish Statistical Dept., *Denmark* 1931.
† Agricultural Census (1929) of France.

The average yield in France in 1860 can hardly have been much below 200 gallons, which would imply a much slower rate of improvement than in Denmark. Admittedly there are individual *Départements* where the standard of farming compares favourably with ours in Britain. Arable farming is good in the *Soissonais* and the *Beauce*; dairying is on a high level in the *Charente*. But these are the exceptions

Clearly the central aims of French agricultural policy have only been partly realized. Self-sufficiency was achieved, but governments failed to promote rural prosperity and efficient farming. France's experience suggests that mere tariffs are not much use without other more positive measures to promote good farming, efficient marketing, and a brisk demand for the farmers' produce. In France's experience the curtailment of imports caused a dwindling of exports (both of food and of manufactured goods), industry developed only slowly, population did not increase much; neither did wages rise; so the total demand for foodstuffs remained static. Consequently farming stayed static too. Nothing boomed; no line was particularly profitable. On the other hand, prices were good enough, thanks to protection, so that all farmers could rub along, making a modest living even though clinging to old-time methods of production. The French, finding themselves in this position and being naturally conservative, did not bother to adopt new methods; nor could they afford new buildings and equipment. No expansion meant no profits, and so no new investment.

We see, therefore, how French agricultural policy largely defeated its own object. It did not preserve a large and prosperous peasantry. One cannot lay the entire blame for this on protectionism, nor can one suggest that free trade, as we knew it in Britain, would have been the panacea. The point that must be stressed here is that protection, by itself, does not turn out so much in the farmer's favour as is often supposed.

Belgium and Switzerland

Both these small countries, in contrast to France, provide examples of peasants who did not count on State assistance but who created organizations of their own for promoting their welfare. Both are countries where farming has been carried on in the face of formidable difficulties, for both have a high density of population and, what is worse, the ratio

of farm population to available farm land has long been extremely unfavourable. In 1880, for example, there were, for each person actively engaged in agriculture, 4 acres of farm land in Belgium, 6 in Switzerland, but nearly 30 in Great Britain. Thus, unless the Swiss and the Belgians produced 6 or 7 times as much per acre as the British, they could not hope to earn as good incomes. Another result of overcrowding was that holdings were unconscionably small. In 1880 there were more than 900,000 holdings in Belgium, but less than 16,000 of these were over 50 acres in size. Switzerland was worse. Even to-day some 90 per cent. of the farm land in both countries is farmed in units of less than 125 acres. Moreover, the individual holdings were (and many still are) hopelessly fragmented. It was, and still is, by no means uncommon to see a farm of 20 acres divided into fifty separate 'parcels' or strips scattered in all directions outside the village and jumbled up among other cultivators' strips.[1]

As a result of these difficulties, and others, the peasants lived in the greatest poverty; they had no agricultural education from which to learn the simplest technical improvements, and did not even enjoy the living example of a few well-cultivated large farms in their midst. They were uncouth, boorish, and ignorant. Yet, from this unpromising soil, two most remarkable organizations sprang into being.

Let us take Belgium first, where the development was entirely due to the initiative and enterprise of the Catholic clergy. In 1890 a certain Abbot Mellaerts founded the 'Boerenbond', a Peasants' Union which has come to occupy a unique place in the agricultural life of the country, at least of the Flemish half. Mellaerts realized that the peasantry could be brought to a higher cultural level only if they were consciously directed by intelligent leaders utilizing a certain element of compulsion. For voluntary co-operation amongst themselves they were not yet fitted. Only the village priest had the necessary prestige and authority to become their leader, guide, and friend. The movement succeeded surprisingly; within five years there were 10,000 members, and by 1934 128,000. The basis is the so-called 'Guild' in each parish, led by the priest, who is often secretary and treasurer as well as spiritual guide; for, as the leaders emphasize, the Guilds exist firstly to promote moral welfare, and after that to further agricultural interests. Each Guild has subsidiary societies: for cattle-breeding, for credit, for purchasing feeding-stuffs, and so on. Each of these is also under the control of the central All-Belgium cattle-breeding society, credit bank, &c.; the Guilds, too, are under a Central Executive Council, which controls not only them but the other central societies as well. The whole organization is highly centralized and authoritarian.

The earliest success of the Boerenbond was in organizing co-operative purchases, especially of feeding-stuffs and fertilizers. It was able to offer notable price reductions, and it rapidly secured a large business. It now manufactures a large proportion of its own feeding-stuffs, and has a financial interest in some of the big fertilizer firms. To establish co-

[1] For a vivid account of fragmentation in Belgium see B. S. Rowntree, *Land and Labour*, p. 122.

operatives for selling farm produce proved more difficult, especially in Belgium, where producer-retailing has always been so prevalent. None the less, a quite important organization has been built up for the sale mainly of eggs, butter, and vegetables. Other activities are co-operative insurance (for live stock as well as for fire and accident), the organization of credit societies, which now have a membership of over 100,000, and a technical service with experts on farm buildings, on electrical installation, on machinery and land drainage, who give advice to local groups. The Boerenbond also sends out demonstrators and lecturers; it organizes winter schools and domestic economy classes; it has a network of rural libraries. Finally, it acts as a focal point for the formulation of agricultural policy, and effectively champions the producers' interests on the public platform and in Parliament.[1]

Without doubt all this activity has most favourably affected the general level of farming. Wheat yields have increased in fifty years from 26 to 39 bushels per acre; the breeds of dairy cattle have been more and more carefully selected, until now average milk yields per cow, at 680 gallons, rank almost equal with the Swiss and Danish. Agricultural education has been popularized until the proportion of the farming population which has had some sort of technical tuition is now higher than anywhere else in Europe, England not excepted. Indeed, the results can be seen in the figures of output per acre:[2]

Net output in 1937

(£ per acre)

Switzerland	15*	Germany	8
Belgium	14	Great Britain	6†
Netherlands	14	Hungary	3
Denmark	10	Poland	2
France	8		

* Reckoning alpine grazings at one-quarter their acreage.
† Reckoning rough grazings at half their acreage.

Despite all the difficulties—the smallness of the holdings and the fragmentation of the land—the Belgians have learned to utilize their soil more intensively than any people in Europe except the Swiss.

Undoubtedly the Boerenbond, whatever its faults, has developed the Flemish cultivator as no other organization could have done. It has won him first on the basis of religious attachment, and has used this to educate him and to draw him into a system of co-operation which he would never voluntarily have accepted. It has enabled him to triumph over adverse circumstances, and to maintain his competitive position without any substantial measures of State assistance. The Belgian peasant has gained in prosperity, status, and self-respect.

[1] For further account of the Boerenbond's activities, see A. Varzim, *Le Boerenbond Belge*.

[2] Net output here means gross output less imported feeding-stuffs, gross output referring to the money value of all produce sold off farms to the non-farming community, plus produce consumed in farm households. For sources of estimates of value of gross output see *Food Production in Western Europe*, p. 516, and, in the case of Hungary and Poland, D. Warriner, *Economics of Peasant Farming*, Oxford University Press, 1939. (The figures for these two countries actually refer to 1935.)

Quite different was the organization of peasants which grew up in Switzerland. Professor Laur, who founded the Swiss Peasants' Union in 1897, realized that the nature of the market for Swiss agricultural produce (largely producer-retailing for home demand) made it impossible for the peasants to organize themselves for production and marketing in such a high degree as those of Denmark. Accordingly, he determined to make good to the peasants in the political sphere what they lost in the economic. The Union was organized first and foremost as a political weapon to obtain from the Federal Government favourable treatment for agriculture. In order to become strong and all-embracing, which indeed it now is, the Union had to be kept non-party and non-sectarian. It includes Catholic and Protestant, conservative and socialist, French, German, and Italian Swiss.

But Laur also realized that, for the Union to remain strong, it could not confine itself merely to political agitation, it must make itself economically useful to the peasantry. So he gradually built up a Secretariat with a statistical and advisory service so excellent that the State prefers to subsidize it rather than run such services of its own. The Secretariat has a staff of 8,000 voluntary market reporters, it publishes weekly and annual periodicals, it undertakes special economic inquiries regarding taxation, farm labour, debts, &c. It has also a Valuations Office whose services are employed to estimate, for inheritance purposes, the value of farms. It has a Buildings Bureau which advises on reconstructing farm buildings. The Union collaborates with the Federal Government in many ways; it sends its own delegates to tariff conferences and to conferences for the negotiation of commercial treaties between Switzerland and other States. In the last war, and in this, the Swiss Government handed over to the Peasants' Union much of the administration of food control and war agricultural policy.

Abroad, Professor Laur has become best known for the organization of farm accountancy, in which he was the pioneer. Swiss farm accounts, though only a few hundred are collected each year, are the most elaborate and meticulously kept of any in Europe.[1] Besides the ordinary farm balance-sheet, detailed information is required concerning the expenditure of the farm family, the consumption of food, purchases of clothes, and other items. Often special costings inquiries are made. The results of all this book-keeping prove immensely valuable in forming the basis of the advisory service, and in providing arguments for use in political debate.

Altogether, the Union, for its size, is quite the most powerful peasant organization in any country. Its successes have been notable and continued. It has popularized the technique of intensive cultivation with the result that Switzerland heads the list of all countries in output per acre (see above table). It has secured for the peasant a comprehensive scheme of protective tariffs and State subsidies, it has greatly improved his standard of living, and has vouchsafed him a larger measure of economic security than any other European cultivator enjoys. There

[1] *Recherches relatives à la rentabilité de l'agriculture suisse.* Annual publications in two volumes.

are, indeed, flies in the ointment—for instance, high prices have led to high land values and, on the strength of these, the peasant has borrowed heavily until he has come to be paying, in mortgage interest, an average of £3 per acre. This represents a really severe burden. Another burden falls on the urban consumer in the shape of dear food, retail food prices being higher than in any other European country. On the other hand, it is due to the efforts of the Peasant Union that Switzerland has preserved her agriculture and has maintained a comparatively high degree of self-sufficiency. She imports less than one-quarter of her food supplies. Although this may have meant dear food and paying for home-grown wheat at three times the world price, the Swiss feel that the Union's policy has now been amply justified. If Germany had occupied the whole of France (as she may yet do) the Swiss would have been entirely dependent on Nazis and Fascists for any imports. Politically they would have been at the Dictators' mercy. But the more self-sufficient they are, the less they have to fear even that contingency. Self-sufficiency may be economic madness; but in a mad world a small country cannot afford to be sane.

Denmark

So much has been written about the farming system of the Danes that it would be impertinent to attempt to summarize the whole story in a few paragraphs. Here we shall discuss only two features, both of which have proved of central importance in that happy history.

The first is the conscious creation, for conscious it has been, of the medium-sized family farm. Denmark has few of the 'dwarf' holdings so abundant in Belgium and Switzerland; she has few large farms; the bulk of her land is cultivated in units of 25 to 125 acres.[1]

Proportion of Agricultural Land in each Size-group

	Over 125 acres	*25 to 125 acres*	*Under 25 acres*
	%	%	%
Great Britain	52	43	5
Denmark	15	78	7
Germany	32	46	22
France	30	50	20
Belgium	12	38	50
Switzerland	7	43	50

Compared with other countries the overwhelming preponderance of medium-sized farms in Denmark is indeed striking.

It is worth examining for a moment how this came about. The enclosure movement of the eighteenth century caused in England a great amalgamation of holdings, but in Denmark the King set himself steadfastly against such trends—'No villages or peasant farms shall be laid waste for the improvement of the farming of the manor.' In those days

[1] Exact comparison is impossible since some censuses include all holdings above 1¼, others all above 1½ acres, and most include many part-time holdings. But though these differences affect the *number* of holdings, they hardly affect the *acreage* at all.

taxation was levied in Denmark on each individual farmstead, and any reduction in their number would have meant a reduction in the King's revenues. But equally there was a danger of farms becoming too small. Again the State intervened. The Government, wishing to prevent too sudden a rural exodus with its consequent vagabondage, forbade the subdivision of farms wherever the resulting pieces were considered too small to support a family. As a result of other decrees, cottars who suffered through enclosure were given extra land in compensation, peasants newly liberated received security of tenure—leases being for fifty years and special loans being made available for those who wished to purchase their holdings.[1] During the nineteenth century the laws against amalgamation continued in force, and those against subdivision were tightened up; consequently the land of each farm, once established in a single block, never fell apart again into fragments. In the 1850's were founded the mortgage associations which completed the work of transforming a nation of tenant cultivators into a community of peasant proprietors. Thus, to-day, Denmark is the only country on the Continent where there is no serious fragmentation into strips, where all the farms remain of a reasonable size, and where there is no great contrast between the largest and the smallest holdings. This has been the basis of the deep-rooted democratic equality among Danish farmers.

The second feature which contributed so much to agricultural prosperity was, of course, co-operation, and it is often asked why co-operation succeeded in Denmark when it failed in most other places. The first reason, as the writer believes, was precisely that all the farms were of a similar size; there persisted no important distinctions of wealth or social class; producers felt a real community of interest one with the other. Secondly, no doubt, because the co-operative movement grew up in the fertile soil of Bishop Grundtvig's revival. Here is no place to describe the Folk High Schools started by Grundtvig in the 1860's and 1870's.[2] Suffice to say that they transformed the sullen, suspicious, and unprogressive peasant into a forward-looking, cheerful, scientifically-minded, resourceful, co-operative individual. Every foreign visitor to Denmark is impressed by the high level of intelligence of the agricultural community, and by the interest which even the humblest farmers and smallholders take in cultural things and in political and economic questions.

It was in the enthusiastic atmosphere of the early days of this educational movement that co-operation made its start; little wonder that it prospered. From the first co-operative dairy in 1882 and the first co-operative bacon factory in 1887, the story was one of uninterrupted development and achievement right down to the beginning of this war. In 1936 over 90 per cent. of the butter trade, 86 per cent. of the bacon production, and two-thirds of the feeding-stuffs purchases were in co-operative hands. This has not merely promoted efficient processing, grading, and marketing, but it has also made possible constant collabora-

[1] See Sir William Ashley's Memorandum in the *Final Report of the Agricultural Tribunal of Investigation.* Cmd., 2145, H.M. Stationery Office, 1924, pp. 244–8.

[2] See Bergtrup, Lund, and Manniche, *The Folk High Schools of Denmark.*

tion between producer and processor in the improvement of quality and in the reduction of costs, both on the farm and at the factory. Moreover, co-operation has extended to farm book-keeping. Denmark is the one country where book-keeping has been organized from the bottom upwards, on the farmers' own initiative, instead of being imposed from above; and no country has such a high proportion of its farmers voluntarily keeping accounts. The Dane always thinks before he acts; he plans production not by rule of thumb but on the evidence of his balance-sheet and in consultation with his agricultural adviser.

The results of all this are widely known. The Danes have been the lowest-cost producers of high-grade food in Europe; they make profits producing milk at 6*d.* per gallon, and they keep 84 per cent. of their farm land under the plough without the help of import duties on cereals or sugar. (In Germany only 68 per cent. is arable, and in France 58 per cent.) Furthermore, the Danes have developed the most labour-saving type of farming on the continent, as the figures for output per man indicate.[1]

Net output in 1937
(£ per head)

Great Britain	200	Switzerland	100
Denmark	155	France	90
Netherlands	120	Germany	70
Belgium	100		

And naturally, since output per man intimately affects the level of earnings, it is not surprising to find the Danes enjoying a higher standard of living than their continental neighbours. The Danish peasants must be reckoned at least 50 per cent. better off than their counterparts in France and Germany.[2] To some extent admittedly this has been due to their fortunate environment. Denmark was not overpopulated, either as a whole or in farming: nearly 16 acres of farm land are available to each agricultural worker. Denmark was within easy reach by sea of the ever-expanding British market. Yet, making all allowances for her good luck, we must give the chief credit to her own progress in efficiency, a progress which could only have been achieved on farms capable of rational cultivation and through organizations which thrived on the intelligent participation of each single producer.

Germany

We turn lastly to a much more recent endeavour to shape agricultural development. The National Socialist Government has, since 1933, tried to carry through a co-ordinated plan for the whole business of food production and food supply, administered through a single body, the *Reichsnährstand*. This task was undertaken from two motives. First, the Nazis wanted to increase food output so as to be as nearly self-

[1] Output per man is calculated by dividing the net output by the number of persons 'engaged in farming'.

[2] This somewhat arbitrary statement would require considerable space for amplification and justification. For more detailed discussion of standards of life see *Food Production in Western Europe*, chaps. 21 and 22.

sufficient as possible. Secondly, they wanted to achieve an iron control of prices, particularly food prices, since they knew that otherwise their planned abolition of unemployment would cause big rises in prices and then in wages, leading easily to inflation. There was also a third, less important, aim—the sociological objective of preserving the peasantry, the fulfilment of Food Minister Darré's 'Blood and Soil' slogan. Apart from grotesque researches into peasants' heredity, the sole innovation of note under this last head has been the Farm Inheritance Law, which makes all farms between 15 and 300 acres inalienable and indivisible. Though in many ways working far from smoothly, this Act at least does away with some of the fragmentation which went on in the south-west.

As for the production campaign, the Germans have certainly developed a comprehensive scheme of advice, persuasion, and compulsion. It starts with land-reclamation schemes, land drainage, and regrouping of fragmented farms. It includes subsidies for new, properly constructed manure-pits; reduced prices for fertilizers; propaganda for more productive crops, e.g. a great extension of the area under roots, under oil-seeds, and under 'catch crops' for fodder or for green manure. Indeed, a slogan that has been coined is 'three crops in two years'. The policy involves special concentration on fodder provision, to make good the loss of imported maize and oilcake; to that end subsidies are given for silo construction, for co-operative potato-steaming plants (since cooked potatoes are stored as pig fodder). It has not forgotten leaflets, lectures, and subsidies for better grassland management, and for the division of pastures into small paddocks for rotational grazing. It includes help to the peasants in maintaining output with the greatly reduced supply of labour, and thus has popularized the 'baby' tractor as well as many types of labour-saving barn machinery. It devotes special attention to live-stock improvement; it has made milk-recording compulsory on every farm where more than three cows are kept; it has laid down that breeding stock are to be judged not on external appearance but on performance. Nor has the statistical side been neglected; book-keeping is now compulsory on all farms of over 250 acres, and a staff of 14,000 economic reporters has been created, who send in monthly particulars of prices, supplies, stocks, wages, crop growth, and so on. This information is mechanically analysed in Berlin, and fifteen days later the Ministry knows exactly the factual position in all districts.

The second great field of activity has been in control of marketing. After first, in 1933-4, raising agricultural prices by some 20 per cent. from the low level of the depression, the Nazis have aimed at preserving fixed prices throughout the system, to the producers, to wholesalers, retailers, and finally to the general public. Farmers' prices for potatoes and cereals are graded first by district and secondly from month to month, e.g. cereals rise by about 6*d*. per hundredweight per month between harvests to cover storage costs and losses. Dealers and retailers work on fixed margins, a method which at first gave rise to difficulties. For instance, it might happen that the price of wheat in one semi-urban zone, A, was 10*s*. per cwt. while the price in zone B, whence zone A obtained much of its supplies, was 9*s*. 6*d*. per cwt., though transport

cost 1*s.* per cwt. Thus, no dealer would send wheat to zone A. Such problems were overcome by pooling of transport costs. For perishables like milk, fruit, and vegetables, collecting depots were set up, and by a great propaganda campaign most of the butter-making was transferred from the farm to the creamery. In the case of commodities liable to sudden gluts and scarcities, such as fruit and green vegetables, it is interesting to see how prices have been maintained. When supplies are scarce and threaten to exceed the maximum price, they are compulsorily shared out among buyers on a quota based on their previous year's purchases. If no bids are forthcoming at the minimum price the local *Reichsnährstand* representative can compel the canning or jam-making firms to buy the surplus at the minimum.

Retail-price fixing and control proved to be the most ticklish problem. Evasions were legion. When hindquarters of beef were fixed higher than forequarters, the point of division crept from the fifth rib up to the shoulder. When dripping (very scarce) was priced at 1*s.* per lb. and liver sausage at 1*s.* 3*d.*, butchers stuffed dripping into their sausage skins and customers gladly paid 1*s.* 3*d.* In order to combat such things, the numbers of regulations, forms, and inspectors have been multiplied unceasingly.

It may be asked how far all this enormous activity has achieved the aims in view. As for output, the time—six years—has been too short for a fair judgement. However, land lost to cultivation for new aerodromes, parade grounds, &c., has more than counterbalanced new land brought into cultivation. Putting cows and pigs on to an unaccustomed and bulkier diet of roots and potatoes, in place of concentrates, has so far more than counterbalanced the improvements by breeding. Almost certainly the soil has been overstrained and has decreased in fertility under the slogan of 'three crops in two years', especially since there has for many years been a shortage of phosphatic fertilizers. As for marketing, there is little evidence of a reduction in distributors' margins. Though distribution has been tidied up—the urban supplies are no longer fetched from so far afield as formerly—the increased costs of administration, inspection, and control have swallowed up the economies.

On the other hand, German farmers soon came to feel a real sense of security. They knew prices for a long way ahead, and could plan accordingly; even gluts did not ruin the market. Further, their farming became progressively more labour-saving—the simple proof being that in five years one million men left the land for industry, yet agricultural output did not decline. That in itself was a notable achievement. Where Nazi agricultural policy became warped was in trying to attain the impossible, namely, complete independence of foreign supplies of both food and feeding-stuffs; to that end, all the principles of good farming were sacrificed and a vast bureaucracy built up which killed more than it created.

Conclusions

In the light of these countries' experience, we may now very briefly consider what their agricultural needs are likely to be in the period of

post-war reconstruction. We have seen the meagre fruits of French protectionism; the sturdy attempts at peasant self-help, despite most unfriendly circumstances, in Belgium and Switzerland; the evolution, under benevolent State direction in Denmark, of a democracy of medium-sized farms on the basis of which co-operation could grow up and flourish; finally, we have seen a gigantic and, in many respects, clumsy attempt at State control of all food production during recent years in Germany. We have seen how much more labour-saving agriculture has become in Britain and Denmark than in France and Germany.

As to the future, the question arises whether a policy can be evolved which will promote good farming, a good living for farmers, and at the same time a rising standard of nutrition for the people as a whole. The writer believes that it can, provided that the fear of war and the feeling of insecurity can be banished from the mind of Europe. As long as nations see a risk of starvation they will, like the Swiss, try to maintain the utmost possible self-sufficiency, even though it involve the maddest measures and very dear food. As long as they fear unemployment in their midst they will reject innovations calculated to produce the same amount of food with less labour. If, however, after this war, conditions can be established on the Continent which provide reasonable security, both political and economic, then a forward-looking agricultural policy immediately becomes possible. A few of the principal features of such a policy may here be singled out.

First, it would seem, food production must to some extent be planned. Farmers, like producers in other industries, can operate more efficiently if they produce at a contract price; even more than other producers they need to be insulated from the crazy ups and downs of world commodity prices; and they need protection from the ruinous effects of seasonal gluts in their own country, especially of fruit and vegetables. All this demands some measure of planning and price-fixing. But there is a deeper reason. Agriculture should expand—if only to meet nutritional needs—yet it will never expand so rapidly as the majority of other industries. Consequently, those other industries will tend to make higher profits and to pay bigger wages. Farming will remain the 'poor relation'. Against this our sense of social justice rebels. The farm worker deserves no worse a standard of life than the factory operative. Given a measure of planning, it might prove possible so to adjust wage rates for labourers, profit margins for farmers, and social services for the rural community as a whole, as in some degree to reduce the 'gap' between town and country. If we prize rural life and rural culture, as we surely do, it should be our steadfast endeavour to improve to an extent that proved quite impossible under *laissez-faire* the nutrition, health, and general welfare of those who work on the land. That is why we need a plan.

Secondly, a principal objective in any policy for Europe must be the amalgamation of all those scattered strips into reasonable-sized family farms. Merely to bring all the farm land of Europe into compact holdings, like those of Denmark, would be an ambitious twenty-year programme. There would be peasant resistance at first, which would

have to be firmly brushed aside. The benefits would be quite stupendous, and the first to recognize them, once the job was done, would be the cultivators themselves. But such a huge enterprise would have to be backed by legislation which prevented fragmentation from ever taking place again. Whether, on the other hand, peasants should be encouraged to combine their holdings into much larger units is not yet a really burning question. In certain exclusively grain-growing areas large units have advantages; but most of western Europe is best suited to mixed live-stock farming, and the most efficient dairying the world has seen is done on medium-sized family farms.

Thirdly, but only after the regrouping has taken place, one can see unlimited scope for the application of modern agricultural science to farming practice. Only when the farm has become a workable unit can the cultivator be expected to apply the knowledge he has learnt from schools and advisers. Very much might be done, even on the basis of existing knowledge, to increase crop-yields, to improve the quality of live stock, to feed animals more scientifically, and to introduce labour-saving methods in every branch of farming. If scientific methods were at all widely adopted on the Continent it would be possible to produce all the necessary food with far less land and far fewer men. All possible ways of disseminating knowledge should be explored; for whilst some peasantries learn most readily from State-sponsored propaganda and education, others learn most through their own co-operative organizations.

Lastly, the State should make it quite clear to the farmers what kinds of food it wants produced. If, as appears indisputable on health grounds, the consumption of protective foods—milk, dairy produce, eggs, and vegetables—ought to be greatly expanded, then the State should encourage farmers to concentrate more and more on those branches of production. Moreover, such a development suits not merely the consumer but is in the peasants' own interest. No producer who is confined to a relatively small acreage, the family farm or less, can earn a tolerable living from the sale of cereals; he must depend mainly on live stock and live-stock products. Indeed, if the nations of Europe wish to retain a large number of small cultivators on the land at a reasonable standard of life, European farming must increasingly be directed to dairying, pig and poultry keeping, fruit and vegetable growing. Such a policy would effectively harmonize the interests of producers and consumers, would facilitate a rising standard of living for both, and would bring about that much delayed marriage between nutrition and agriculture.

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QUALITY IN RICE

A. SREENIVASAN

(Institute of Plant Industry, Indore; formerly Rice Research Biochemist, Indian Institute of Science, Bangalore)

NEXT to wheat rice is the most abundant grain crop of the world [1]. Numerous varieties exist and fresh additions are being made continuously. Some varieties are distinguished by their high yield, others by good milling quality, keeping or cooking properties, fine taste, pleasing appearance, fitness to a variety of soil and climatic conditions, resistance to pests and diseases, and in various other ways.

Improvements in rice culture have hitherto aimed at increasing yields, and sufficient stress has not been laid on improving the nutritive value of rice varieties. Indeed, rice as an article of food is considered poorer than other cereals. This paper examines, in the light of recent scientific work, the changes in chemical composition of rice due to (i) varietal, cultural, and environmental differences, and (ii) polishing, parboiling, and cooking. The interrelation of composition and nutritive value of rice is then discussed and means of improvement suggested.

Chemical Composition of Rices

(*a*) *Comparison with other cereals.*—In Table 1 the average composition of rice is compared with that of other common cereals.

TABLE 1. *Composition of Cereals (per cent.)* [2, 3, 4]

	Water	*Proteins*	*Fats*	*Carbo-hydrates*	*Celluloses*	*Minerals*
Rice: (*Oryza sativa*)	11·6	9·1	2·4	74·8	0·7	1·4
Wheat: (*Triticum sp.*)	12·0	11·6	1·5	71·2	2·2	1·5
Bajra or Cumbu-Pearl millet: (*Pennisetum typhoideum*)	11·3	10·4	3·3	71·8	1·2	2·0
Barley: (*Hordeum vulgare*)	12·5	11·5	1·3	69·3	3·9	1·5
Jowar—Great millet: (*Sorghum vulgare*)	11·9	10·4	1·9	74·0	..	1·8
Maize—Indian corn: (*Zea mays*)	13·1	8·6	3·8	71·3	1·9	1·3
Ragi—African millet: (*Eleusine coracana*)	13·2	7·3	1·5	73·2	2·5	2·3
Rye: (*Secale cereale*)	11·6	10·6	1·7	72·6	1·7	1·9
Common millet: (*Panicum miliaceum*)	9·4	11·6	3·3	63·0	10·0	2·9

Carbohydrates predominate in rice as in all other cereals. Protein-content is comparatively low, and like other cereals, rice contains only small amounts of fat and mineral matter, but the value of these is by no means negligible because of the very large quantities of rice consumed.

(*b*) *Variation in composition.*—Despite the bewildering number of rice varieties, the average values for the different constituents as reported by several investigators fall, with few exceptions, within a narrow range (Table 2).

TABLE 2. *Average Chemical Composition of (unpolished) Rice*

Percentages on oven-dry basis

Rice from	*Proteins*	*Ether extract.*	*Fibre*	*Carbo-hydrates*	*Ash*	P_2O_5	*CaO*	*Source*
India (Bihar) .	8·51	2·68	0·86	86·14	1·82	0·80	..	[5]
India (Bengal)	8·31	2·14	0·70	87·54	1·39	0·75	0·05	[6]
India (Madras)	7·46	2·67	0·61	86·86	1·53	0·84	0·08	[7]
Burma . .	8·07	2·57	0·84	86·89	1·63	0·76	0·03	[8]
Ceylon . .	10·30	2·74	0·73	84·63	1·59	0·81	0·07	[4]
Japan . .	9·40	3·14	1·39	84·55	1·52	..	..	[9]
Hawaii . .	8·28	2·47	3·18	84·53	1·54	..	..	[10]
America. .	10·40	2·28	1·23	84·86	1·25	..	..	[11]

Between individual samples, however, the composition varies rather widely [6, 7, 11, 12, 13, 14, 15]. Of special significance is the recent observation [7] that, of several varieties from southern India, the coloured and coarse-grained varieties are generally richer in proteins and minerals, particularly phosphorus, calcium, and iron, than the fine-grained and white varieties which fetch the highest prices. Also, polishing trials have shown that to produce a grain of equal whiteness from the different rices, a higher degree of polish is required by the coarser ones. They therefore contain thicker bran layers than the others. These observations have been supported by independent histological examination [16, 17].

(*c*) *Influence of manuring.*—Similarly to barley and wheat, the protein and mineral contents of rice can be increased by the use of suitable fertilizers. The author determined these contents in samples of two varieties grown with different manures at two research stations in south India, Coimbatore and Pattambi, and found [7] that the protein-content of husked unpolished grain can be considerably enriched (up to 20 per cent.), especially if nitrogen is applied in several doses up to the flowering stage. This improvement was obtained without detriment to yield, which, in fact, increased [18].

(*d*) *Duration of crop.*—The life of the common rice varieties is usually 3–8 months between sowing and harvesting. Late varieties are high yielders, but early ones may be chosen (i) because of limits imposed by climate, or (ii) to obtain larger profits if irrigation facilities exist for two or more successive rice crops. Early rice varieties are considered poorer, because they are supposed to remove less plant-food from the soil [6, 19, 20, 21]. In south India, at any rate, there are many short-duration varieties that are richer in nutrients than the late ones [7].

(*e*) *Dry and wet cultivated rices.*—Rice is essentially a wet crop and requires prolonged swamping during the major part of its period of growth. There are, however, some dry varieties grown in parts of India and elsewhere that fit in well with the local cropping systems. Dry

cultivated rice is less productive than irrigated swamp-grown rice, but McCarrison [22] considers it to be the more nutritious. This does not apply when the same variety is grown under dry as well as swamp conditions: the swamp-grown crop contains greater percentages of protein and mineral matter than the dry crop (Table 3). The aleurone layers are also better developed [17].

TABLE 3. *Composition of Dry and Wet Cultivated Rices*

Mode of cultivation	*Yield, lb. per acre*	*Proteins*	*Minerals (total)*	P_2O_5
		Per cent. on dry basis		
		Variety—Dirty modan		
Transplanted—swamp . .	1,400	12·25	1·67	0·81
Broadcast—dry	824	9·21	1·39	0·72
		Variety—Black modan		
Transplanted—swamp . .	1,434	11·63	1·66	0·83
Broadcast—dry	783	9·42	1·43	0·72
		Variety—Katta modan		
Transplanted—swamp . .	1,734	11·41	1·68	0·79
Broadcast—dry	740	8·89	1·51	0·70

Preparation for the Market and the Table

(*a*) *Polishing.*—Exported rice and a large part of the rice used for home consumption is milled and polished. In polishing the bran layer is almost entirely removed. The outer envelope or bran and the germ portion together constitute nearly one-eighth of the whole grain, the remainder being the endosperm or polished rice (Table 4). The bran, however, contains more than half the mineral matter of the whole grain,

TABLE 4. *Distribution of Nitrogen and Phosphorus in the Grain*

Part of grain	*Variety—Adt 11*			*Variety—Co 9*		
	Per cent. by wt.	*Per cent. distribution of*		*Per cent. by wt.*	*Per cent. distribution of*	
		Nitrogen	*Phosphorus*		*Nitrogen*	*Phosphorus*
Germ (embryo)	1·2	1·8	7·3	1·4	2·0	8·5
Bran (pericarp)	9·3	19·9	44·2	11·8	19·3	61·5
Polished rice (endosperm)	89·5	78·3	48·5	86·8	78·7	30·0

a fourth of the proteins, and practically all the fats and vitamins. Numerous workers have drawn attention to the high concentrations of essential nutrients found both in the outer coats and in the germ or embryo, and also to the waste associated with the process of polishing [23].

(*b*) *Parboiling.*—In many rice-growing countries a part of the output of paddy, especially of certain varieties, is parboiled before milling. In this process the cleaned paddy is soaked in water for a definite period

and afterwards steamed till the husk just begins to burst. The steamed paddy is dried and milled.

Attention has recently been drawn to the relatively high antineuritic and nutritive value of parboiled rice, even after moderate polishing [24, 25, 26, 27, 28]. The scientific interpretation was given by Aykroyd [29], who showed that, during the process of parboiling, there was a diffusion of vitamin B_1 from the germ and pericarp into the endosperm. This was followed by the discovery [23] that the endosperm also absorbs a little of the protein and mineral constituents from the integuments. Polished, parboiled rice was thus found to be a little richer in essential constituents than the same rice polished raw. Further, the parboiled rice of commerce is often prepared exclusively from the coarse varieties (with thicker layers of the richer bran) which do not mill well when raw [30]. Recently, however, parboiling has been found to suit fine varieties as well [31]. Another point of interest is that the parboiled rice of commerce is generally undermilled, being less easy to polish than raw rice [7]. It is also possible that parboiled rice is not polished to a very high degree of whiteness because parboiling produces translucency and creamy colour in the grain.

(*c*) *Mode of preparation.*—In preparing rice for food the grain as a rule is repeatedly washed in running water before it is cooked, by adding it to water kept nearly boiling. When cooking is complete, as shown by the swelling and consistency of the grains, the excess of water is drained off. Washing and discarding of the surplus water after cooking have been repeatedly condemned by health propagandists [23, 28, 32, 33, 34], as these processes involve loss of the valuable proteins, minerals, and vitamins. The surplus water after cooking is often fed to cattle. Of late, in many well-regulated households only enough water is used to enable the rice to cook to its proper condition. This is a distinct improvement. The losses on washing, which are not yet well known, are even more wasteful. Washing is necessitated by the presence of natural impurities as well as of extraneous substances used to glaze the grain. Washing can be safely dispensed with, or at least reduced to a minimum, provided it becomes possible through legislation or otherwise to prevent the use of harmful materials in preparing rice for the market.

TABLE 5. *Percentage Losses of Proteins and Phosphorus Compounds on Washing and on Cooking*

Degree of polishing	*Washed rice*		*Cooked rice*	
	N	P	N	P
	Variety—Adt 11			
Unpolished	3·3	17·5	2·9	13·8
Semi-polished (5 per cent.)*	4·3	14·6	4·3	14·6
Polished (10 per cent.)*	3·7	18·2	8·1	17·1
	Variety—Co 9			
Unpolished	2·3	18·6	1·0	12·6
Semi-polished (5 per cent.)*	3·3	18·1	2·8	
Polished (10 per cent.)*	4·4	21·0	5·2	18·6

* Exclusive of the losses on polishing.

Nutritive Properties

(*a*) *Protein.*—It is well known that rice protein is highly nutritious and contains all the essential amino-acids [35]; indeed, in its general amino-acid make-up, it resembles the majority of the proteins of meat, milk, and the soya bean [36]. The biological value of the protein of rice is about 86 as compared with 67 for wheat [37, 38, 39, 40, 41]. For the maintenance of nitrogen equilibrium, rice protein is superior to wheat protein and appears to be as effective as the animal proteins [42]. This justifies, to some extent, the extensive use of rice as an article of diet in spite of its somewhat low protein-content. Recent work has shown that the biological value of the protein of rice in a mixed diet is greatly increased by the addition of supplements of calcium [43, 44]. Addition of skimmed milk, or calcium lactate, has also been shown to enhance greatly the nutritive value of rice [45, 46].

(*b*) *Calcium and phosphorus.*—Rice is deficient in calcium (about 0·07 per cent. CaO), but is a very good source of phosphorus (about 0·75 per cent. P_2O_5), which is present mostly in organic combination as phytin [44, 48, 49]. In this form it is not easily assimilable by the animal organism [50, 51]. The rachitogenic action of cereal diets is said to be due to this cause [52, 53, 54]. There is, however, some recent evidence which suggests that the phosphorus in rice is not entirely unavailable [55].

In rice the calcium-phosphorus ratio of approximately 1:10 is not well suited to the needs of the animal body, which are better met by a ratio of 1:1 or 2 [56]. Hence, supplements of calcium, as milk, vegetables, and other foods, can favourably influence the assimilation of the phosphorus compounds of rice. Leafy vegetables in particular contain more calcium than phosphorus [3], and have in fact an unbalanced mineral ratio almost the reverse of that in rice, so that the addition of vegetables to a ration containing rice will balance the mineral ratio. Vegetables, when taken raw, are also a good source of phytase [49], which hydrolyses and renders available the phytin of rice. Rice itself contains a trace of this enzyme [57]. The probable presence of a phytase in the intestines of human and animal organisms has recently been investigated [58], but so far the evidence is mainly inconclusive [59]. It will, if proved, provide another means for effecting the efficient assimilation of rice phosphorus.

(*c*) *Iron.*—The iron-content of rice is rather small (about 5–10 mg. per 100 gm.), yet, as a source of iron, rice assumes importance in consequence of the large amounts consumed. It is noteworthy that most coloured rices contain more than two to three times the quantity of iron normally present in rice varieties [60].

(*d*) *Fats and vitamins.*—Rice oil is considered to be quite nutritious [61], and it is important as the carrier of vitamin E [62, 63]. Rice, especially the bran layers, has been long recognized as among the richest sources of vitamin B_1. It also contains a small amount of vitamin A [64, 65].

(*e*) *Nutritive value.*—The results of extensive feeding experiments carried out by the author with young rats and pigeons, fed on different

varieties of rice as the sole source of proteins and minerals in an otherwise adequate diet, have shown that significant differences in growth-rates obtained with the varieties are essentially related to their composition. A few typical results are given in Table 6.

TABLE 6. *Average Growth-rates of Rats fed with Different Rice Varieties: Mean Increase in Weight per Rat per Week*

Variety	*Duration of crop (days)*	*Proteins*	*Total minerals*	P_2O_5	*CaO*	*Number of rats used*	*Average weekly increase (gm.) during 7 weeks*
		Percentages on dry basis					
Adt 3	104	10·47	1·62	0·82	0·12	5	7·49
Co 9	123	9·59	1·76	0·73	0·10	4	6·96
Co 10	119	7·61	1·65	0·79	0·06	5	5·97
Adt 7	237	7·26	1·70	0·56	0·13	4	4·74
GEB 24	140	6·97	1·66	0·54	0·07	5	4·88
Adt 11	172	6·59	1·46	0·70	0·09	6	4·10

Standard error per rat = 0·27 gm. = 4·8 per cent. of general mean.

The mean average weekly increase in weight per rat was found to be highly correlated ($r = +0{\cdot}9608$, $P < 0{\cdot}01$) with the protein-content of the varieties, but not significantly with the phosphate-content (actual $r = +0{\cdot}6910$, $P > 0{\cdot}1$). In other work, in which 15 rice samples were examined, highly significant correlations were obtained between the average growth-rates induced in young rats by the different rices and their respective contents of nitrogen and phosphorus. The correlation coefficient of mean weight-increase and nitrogen-content was slightly lowered when the effect due to phosphorus was eliminated, whilst that for phosphorus-content fell considerably when the nitrogen-content was kept constant. This would suggest that growth is mainly influenced by the nitrogen-content of the rice varieties and only slightly so by the phosphorus-content. It is also noteworthy that, for the varieties examined, close correlation subsisted between the contents of nitrogen and phosphorus.

Of the six varieties (Table 6) the first three (Adt 3, Co 9, and Co 10) are of shorter duration and smaller than the others. The results on growth-rate with these varieties therefore support the earlier observation (p. 185) that short-duration crops are not necessarily inferior to long-duration ones.

The results of similar growth-experiments with dry and wet cultivated rices also support the earlier conclusion (Table 3) regarding the superior nutritive value of swamp-grown rices (Table 7).

(*f*) *Digestibility of unpolished and polished rices.*—Recent experiments on the digestibility *in vitro* of cooked grains have shown that, contrary to general belief, the difference in digestibility between cooked unpolished and polished rices is too small to be of any significance in practice [66]. Unpolished rice is richer in nutritive ingredients than polished rice, and it does not swell on cooking to the same extent. Hence, bulk for bulk, it contains more solid matter and has therefore to be taken in smaller quantities.

TABLE 7. *Nutritive Value of Dry and Swamp-grown Rices: Mean Increase in Weight per Week per Rat*

Mode of cultivation	*Number of rats used*	*Average weekly growth-rate during 7 weeks (grams)*
	Variety—Dirty modan	
Transplanted—swamp	4	8·18
Broadcast—dry	5	5·88
	Variety—Black modan	
Transplanted—swamp	3	7·43
Broadcast—dry	4	5·39
	Variety—Katta modan	
Transplanted—swamp	3	7·04
Broadcast—dry	4	4·68

Standard error per rat = 0·27 gm. = 4·8 per cent. of general mean.

Conclusions

(*a*) *Factors tending to lower the food-value of rice.*—The foregoing considerations indicate that the poor quality of the rice eaten by a large section of the population is traceable to (i) the prevailing taste for fine, white, and small or long-grained varieties; (ii) the process of polishing, which removes the major part of the protein and phosphorus compounds as well as the essential vitamin; (iii) the practice of thorough washing before cooking, which removes a further part of the residual bran; and (iv) the present method of cooking, involving loss of gruel containing essential food ingredients.

(*b*) *Rice* v. *wheat.*—It has been frequently stated that wheat is more health-sustaining than rice [67]. If, however, the comparison be made on the basis of identical dietary proportions of the *whole* (unpolished) grains, rice approaches wheat in nutritive value. Although wheat is richer in proteins and minerals, rice protein is more assimilable. Also, varieties of rice compare favourably with wheat in regard to composition, and it is possible to enhance, to some extent, the nutritive value of rice by manuring. As a staple food rice has a higher calorific value than wheat, although, as observed by Wilson [68], rice, when ready for consumption, is bulkier and contains more water than a quantity of wheat of equal calorific value; the higher water-content of rice may be advantageous in a tropical climate, since it provides a better reservoir of water for skin evaporation and urine secretion, thus regulating body-temperature.

(*c*) *Why polished rice is favoured.*—The one feature that distinguishes rice from wheat and all other cereals is that it is predominantly consumed in the polished state. In spite of the food-value it loses by polishing, polished rice is nearly everywhere preferred. The reason is not far to seek. Polished rice has a pleasing appearance and texture, it cooks more easily than the unpolished grain, and in the raw condition it keeps far better and can be stored for long periods or transported over long distances without appreciable deterioration. The last quality

is the one which appeals to the largest section of both producers and consumers. It is, in fact, the chief reason which militates against the introduction of any major legislation to check the wholesale replacement of unpolished rice by the polished product. The poor keeping-quality of unpolished rice is essentially due to the rice oil contained in the embryo and the outer integuments of the grain [61, 69]. It is possible, by suitable control of humidity and storage, to prevent or minimize the deterioration of hulled rice on storage [70], but there is great need for evolving improved methods that are readily applicable in practice.

It may not be quite practical to ask people to go back to hand-pounded rice, but even a lower degree of milling would do a great deal of good. It should be possible, by proper control measures and propaganda, to check the wholesale displacement of unmilled rice by the highly milled product, and to encourage undermilling. The League of Nations Inter-Governmental Conference on Rural Hygiene has rightly emphasized that 'the problem of nutrition throughout the East is intimately connected with the degree of milling to which rice is subjected before being consumed'.

Although rice is mainly consumed as cooked grains, there are certain localities where pancakes are prepared from the flour. As this method of preparation necessarily does away with the washing and cooking losses, there is much to be said in its favour.

(*d*) *Rice bran as food.*—Another line of improvement would be to popularize the use of rice bran as an article of food. Bran flours are considered to be quite nutritious and are very popular in the United States and elsewhere. This would naturally suggest the use of rice-polishings for human consumption, especially as they are very much cheaper than the flour. The reason that rice bran has not become popular is that it contains a vegetable fatty oil which becomes rancid if the bran is stored indifferently. The most convenient method for preserving rice polish is to heat it when fresh at 50°–60° C., and then keep it in moisture-proof containers. Heating removes some moisture, stops the destructive action of enzymes, destroys any mould spores, insects, or insect eggs which may be present in the bran, but does not affect the vitamin. Bran treated in this manner has a pleasant flavour which, if necessary, can be diluted or toned down by suitable additions of wheat or other flour. Such mixtures of bran and flour can be used for preparing a variety of food articles, such as bread, cakes, pastries, and biscuits. Indeed, rice bran, exported from India in large quantities, is used for such purposes.

(*e*) *Rice in a well-balanced diet.*—Suitable proportions of meat, milk, eggs, butter, vegetables, fruits, and other protective foods will no doubt supply essential dietary elements lacking in polished rice. They cannot, however, always be had, either on account of poverty or for sentimental reasons, so that other cheap and adequate accessories must be found [71], and be intelligently incorporated in the food. The use of rice bran as a food would help to supply the deficiency present in diets consisting largely of polished rice. Increased use of whole, unmilled, or under-milled rice, especially from coloured or coarse varieties known to be rich

in nutrients, will also greatly improve the customary rice diet, and will result in better growth and greater improvement in the general health and well-being of the rice-eating peoples.

Summary

1. Rice contains less protein and minerals than many other cereals. Individual rice varieties, however, vary considerably in chemical composition. In particular, coloured and coarse varieties contain more albuminoid and mineral matter than the fine ones, and they possess thicker bran-layers.

2. The possibility of increasing the protein and mineral contents of the rice grain by fertilizer applications has been indicated from analyses of rice produced in manurial tests.

3. Contrary to the popular belief, there are many short-duration varieties of rice which have a chemical composition better than some of the long-duration ones; wet cultivated rice is superior in composition to dry cultivated rice.

4. The process of polishing removes from the rice grain about 25 per cent. of the protein, 60 per cent. of the minerals, and all the fats and vitamins.

5. Parboiled rice retains after polishing more vitamin B_1, protein, and minerals than raw rice.

6. The prevailing practices of washing and cooking rice result in appreciable losses of protein and phosphorus compounds.

7. Rice protein is highly nutritious and has a biological value higher than that of wheat. Supplements of calcium greatly increase the availability of protein and mineral constituents of rice.

8. Growth of young rats and pigeons fed on different varieties of rice is essentially correlated with their contents of protein and phosphorus compounds.

9. The bearing of the above observations on (i) the nutritive value of rice as ordinarily consumed, and (ii) the scope for improving the rice diet, is discussed.

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THE ROTHAMSTED EXPERIMENTS ON THE MANURING OF POTATOES

PART I. EFFECTS OF NITROGENOUS, PHOSPHATIC AND POTASSIC MANURING

SIR E. J. RUSSELL AND H. V. GARNER

(*Rothamsted Experimental Station, Harpenden, England*)

THE Rothamsted experiments on the manuring of potatoes did not begin till 1876. In the early days at Rothamsted potatoes had not been important as a farm crop, but the area had steadily expanded and by 1876 no less than 348,000 acres were grown in England and Wales.[1] Little was known, however, of the most suitable manuring for the crop: in good practice large dressings of farm-yard manure, even up to 30 tons per acre, were given, and also considerable quantities of artificials—up to 10 cwt. per acre, chiefly superphosphate or guano but sometimes also potash and nitrogen; there was, however, no great uniformity.

Two problems were studied: (i) the relative effects of nitrogenous, mineral, and farm-yard manure on the yield and composition of the potato; (ii) the influence of manuring on potato disease, this being of particular importance because *Phytophthora* was widespread, and spraying with a copper mixture had not yet come into use against it.

Gilbert discussed the results of the first twelve years of the experiments in a lecture given at Cirencester[2] but not in his summary, *Fifty Years Experiments*. The plan of the experiment was very simple: it consisted of ten plots in Hoosfield, and the results are set out in Table 1. The following conclusions were drawn. A complete fertilizer is essential. Nitrogen alone, whether supplied as ammonium salts or nitrate of soda, gives less increase than minerals alone, in contradistinction to mangolds where the nitrogen alone and minerals alone had given approximately the same increase; and to wheat and barley, where nitrogen alone had given a much larger increase than minerals alone. The combination of nitrogen and minerals gave a considerably better result, a full average yield, in fact, and again in contrast with other farm crops, ammonium salts was as effective as nitrate of soda.

[1] The marked change in importance of the potato crop is shown by the following acreages for England and Wales in 1876 and 1938:

	1876	*1938*
Area of potatoes . . .	348,010	474,786
Total arable area . . .	14,527,144	8,877,712
Percentage under potatoes .	2·40	5·35
Yield per acre . . .	5·8*	7·3

* Mean 1885–94. No earlier figures published. *Bd. Agric. Returns*, 1894, p. xxvii.

[2] J. H. Gilbert, *Agric. Stud. Gazette*, Cirencester, 1888, **4**. Rothamsted Memoirs, **6**.

TABLE 1. *Yield of Potatoes, 12 years, 1876–87; and Percentage of Diseased Tubers*

Artificials only	*Yield, tons per acre*			*Percentage of diseased tubers*		
	No minerals	*Super.*	*Super. +K, Na, and Mg*	*No minerals*	*Super.*	*Super. +K, Na, and Mg*
No nitrogen . .	2·0	3·67	3·76	3	4	3·5
N as ammonium salts*	2·29	..	6·72	4	..	6
N as nitrate of soda .	2·62	..	6·65	5	..	7

Farm-yard manure series	*No manure*	*Farm-yard manure*	*Farm-yard manure + super.*	*Farm-yard manure + super. + nitrate of soda*
1st 6 years 1876–81				
Yield, tons per acre .	2·28	5·23	5·58	7·22
Percentage diseased .	4	5·5	6·7	12·5
2nd 6 years 1882–7	*No manure*	*No manure*	*Farm-yard manure only*	*Farm-yard manure only*
Yield, tons per acre .	1·69	3·05	6·26	4·01
Percentage diseased .	1·5	3	2·5	2

* A mixture of equal weights of sulphate of ammonia and muriate of ammonia supplying 86 lb. N per acre, as also did the nitrate of soda in both series of experiments.

The farm-yard-manure plots are best treated separately because of a change made in the manuring. Used alone farm-yard manure gave less yield than did complete artificials, as also did farm-yard manure + superphosphate; but when nitrate of soda was given in addition the yield rose to its maximum, 7·22 tons per acre. This was above the average yield of the time, and taken in conjunction with the recognized unsuitability of the Rothamsted soil for potatoes, it showed the effectiveness of this combination of fertilizers.

The design of the experiment does not allow a separation of the potash and the phosphate effects, and whilst recognizing the importance of potash for the production of starch, Gilbert considered that the experiments supported a manuring of dung, phosphate, and nitrogen. The discontinuance of nitrate caused a sharp reduction in yield: the small rise after omitting the superphosphate may be seasonal.

The percentage of diseased tubers varied with the luxuriance of growth: it was low (3 per cent.) on the unmanured plot and increased with the yield, rising to 12·5 per cent. on the plot receiving farm-yard manure, superphosphate, and nitrate of soda. Potash and phosphate did not reduce the liability to disease, and nitrogenous manuring increased it, though the experiment does not show whether this is the result of some modification in the composition or structure of the leaf-cell, or simply the result of the extra leaf-area.

There was a small but not very pronounced deterioration of yield. The unmanured plot which had begun with a yield of 2·6 tons for the

first four years, gave in the last five years only 1 ton per acre; but the variations in yield on the completely manured plots had not been more than could be attributed to fluctuations of season or differences in varieties. Nor was there any evidence that disease was accumulating; the percentage of affected tubers showed no tendency to rise.

The experiment was discontinued in 1901 because it was then clear that the new heavy-yielding varieties of potatoes responded well to potassic fertilizers, and it was necessary to study these in relation to the nitrogenous fertilizers.

The Modern Experiments at Rothamsted and Outside Centres

The modern experiments fall into two groups: continuous and shifting.

The continuous experiments.—These are made on the same land each year, but they are so designed as to eliminate the soil deterioration which complicates the classical experiments. This necessitates a rotation of crops and of treatments, and the two rotations have to be out of step. The cycle thus takes a long period to complete; in the meantime although full discussion of the results is not possible, much useful information is obtained which steadily grows in value. There are three sets of experiments in this group.

(1) *The six-course rotation* begun in 1930. The purpose is to show in their simplest form the responses to increasing amounts of each of the three main fertilizers. The data will be of particular value for the study of seasonal conditions. The order of cropping is: potatoes–rye–sugar-beet–barley–clover–wheat. There are 15 manurial treatments:

0 N, 1 N, 2 N, 3 N, 4 N each with 2 units P and K;
0 P, 1 P, 2 P, 3 P, 4 P each with 2 units N and K;
0 K, 1 K, 2 K, 3 K, 4 K each with 2 units N and P;

the single doses (1 N, 1 P, 1 K) being 0·15 cwt. N, 0·15 cwt. P_2O_5, and 0·25 cwt. K_2O per acre. Within each of the three sets, the treatments 4, 3, 2, 1, 0 units follow each other in that order in successive years.[1] There are thus 15 plots for each crop, and 90 plots in all. The plots are not duplicated and there is no unmanured plot. No organic manure is given. The cycle is completed in 30 years, after which each plot will have completed 5 rotations by crops and 2 by treatments. The experiment is made both at Rothamsted and Woburn.

(2) *The four-course rotation* begun in 1930. The order of cropping is: potatoes–barley–rye-grass–wheat. The object is to study the effect of organic manures: farm-yard manure; straw compost; and straw ploughed in with the appropriate artificials, in comparison with artificial fertilizers. Any given plot receives always the same treatment, but the treatment is applied only once in 5 years; information is thus obtained about the effect of the fertilizer in the year of application and also in the first, second, third, and fourth years after application.[2] The cycle is completed in 20 years. This experiment is made at Rothamsted only.

(3) *The three-course rotation*: potatoes–barley–sugar-beet. The pur-

[1] For details see *Rothamsted Ann. Rept.*, 1932, p. 131.
[2] For details see *Rothamsted Ann. Rept.*, 1932, p. 127.

pose is to compare straw compost with straw ploughed in with artificials.[1]

Shifting experiments.—The purpose of these is to study the manurial problems arising in actual farm practice, and they are therefore made on the ordinary farm at Rothamsted and Woburn and at a number of outside centres, mostly on the farms of good potato-growers south of the Humber and east of the Severn. Information has been obtained about the response to the three groups of fertilizers under various conditions of soil and climate, and the extent to which these responses have been affected by farm-yard manure and by the various cultivation devices. The experiments differ from the continuous series in that neither the site nor the design of the experiment has remained constant. The experiments are made under ordinary farm conditions on the field where potatoes happen to be growing; and as the method of making field experiments was improved, so the improvements were carried into the experimental design. The first experiments were on single plots, then came simple replicated experiments, and finally the modern, more complex types of factorial experiments. These are of various designs, but a frequent and useful one has 27 plots testing the effect of the three fertilizers each at three levels, 0, 1, and 2 doses.[2] The results are not strictly comparable with those of the older simpler experiments. The older figures show what the fertilizer did in certain conditions usually approximating to those in good practice; in particular the other nutrients were generally present in adequate amounts. The modern experiments usually include a number of treatments which would certainly not be recommended in practice but are included to measure the interdependence of fertilizer effects. When all these treatments are averaged so as to include those in which certain essential factors are omitted, the final figure is lower than it would be in a simple experiment of the old type. The results of the Rothamsted experiments as given in the following pages are only about two-thirds of what they would be if one confined attention solely to those plots receiving full quantities of the other nutrients, and which more resemble the conditions of good practice. The comparison is as follows:

	Mean response as given in tables and involving many comparisons		*Response in presence of adequate basal nutrients*	
	No dung	*Dung*	*No dung*	*Dung*
Nitrogen (0·25 cwt. N)	1·11 (8)	1·08 (10)	1·58 (8)	1·33 (10)
Phosphate (0·5 cwt. P_2O_5)	0·80 (4)	0·61 (6)	1·72 (4)	1·09 (6)
Potash (0·5 cwt. K_2O)	1·07 (5)	0·40 (8)	1·50 (5)	0·63 (8)

The figures in brackets are the numbers of experiments. Responses in tons per acre.

There are considerable objections to picking out certain plots in this way,

[1] For details see *Rothamsted Ann. Rept.*, 1933, p. 118.
[2] As illustration, see *Rothamsted Ann. Rept.*, 1933, p. 175.

and it is much safer to use the mean figures even though the result is lower than would be obtained in practice.

During the course of the work the fertilizer dressings have changed and where it has been desired to reduce the results to comparable form the formula of Crowther and Yates[1] has been used. These values can be distinguished from the actual experimental data since they are always given as the 'calculated increase' from 0·25 cwt. N, or from 0·5 cwt. P_2O_5, or from 0·5 cwt. K_2O per acre, as the case may be.

Effect of Nitrogenous Fertilizers on the Yield of Potatoes

It is unnecessary to give details of the first series of experiments. Table 2 shows the results of a replicated set of experiments carried out at Rothamsted for 7 successive years, 1925–31.

TABLE 2. *Effect of Sulphate of Ammonia on Yield of Potatoes*
Tons per acre, Rothamsted[2]

1st series. 7 years 1925–31.[3]

Yield without sulph. amm.	*Additional yield for sulph. amm.*		*Calculated increase for 0·25 cwt.* N
	One dose	*Two doses*	
7·37	1·10	1·70	1·12

2nd series. 1932–40.

	No farm-yard manure			*Farm-yard manure*				
	Yield without sulph.	*Additional yield for sulph. amm. cwt. per acre*		*Yield without sulph.*	*Additional yield for sulph. amm. cwt. per acre*		*Calculated increase for 0·25 cwt.* N	
Year	*amm.*	*2*	*4*	*amm.*	*2*	*4*	*No dung*	*Dung*
1932	9·32	1·85	3·17	10·24	2·34	3·22	1·54	1·74
1934	8·95	1·35	1·65	11·02	1·59	1·88	0·94	1·10
1935	5·56	..	2·57	7·10	..	2·06	1·39	1·11
1936	4·83	1·30	..	7·06	0·24	..	0·96	0·18
1937	4·59	1·85	2·87	6·84	1·89	3·46	1·46	1·63
1938	9·16	0·92	2·68	12·28	1·42	2·22	1·06	1·12
1939	5·93	1·99	1·86	9·70	1·46	2·14	1·24	1·12
1940	7·52	0·40†		8·83	0·72†		0·24	0·43
Mean increase*	7·59	1·59	2·45	10·01	1·74	2·37	1·25 1·10‡	1·34 1·04‡

* Omitting 1935, 1936, and 1940, when only single doses were given.
† 0·6 cwt. N = 3 cwt. sulphate of ammonia approximately.
‡ Mean of all results (8 expts.).

[1] E. M. Crowther and F. Yates, this Journal, 1941, **9**, 77–97. This equation gives similar results to that of Mitscherlich for P_2O_5 and K_2O, but considerably different values for nitrogen.

[2] In all the Rothamsted experiments the potatoes are grown in rows 27 in. apart and spaced at 2 links (15·8 in.); there would thus be 14,670 plants per acre if all survived. Great care is taken about seed and cultivations, and the loss of plant is small.

[3] The figures are the means of all potash and phosphate treatments. Dung was given in each year except 1925 and 1931.

Six-course rotation: no dung: average 11 years 1930–40.

	Yield without sulph. amm.	*Additional yield for* N *as sulph. amm.*			
		0·15 cwt. N	*0·30 cwt.* N	*0·45 cwt.* N	*0·60 cwt.* N
Rothamsted .	5·79	0·75	0·83	0·86	1·27
Woburn . .	6·31	0·86	1·66	2·65	2·67

(0·15 cwt. N = 0·75 cwt. sulphate of ammonia)

Increasing the dressing of sulphate of ammonia increases the yield, though not as a rule proportionately; in most years the increase given by 4 cwt. of the fertilizer would be profitable.

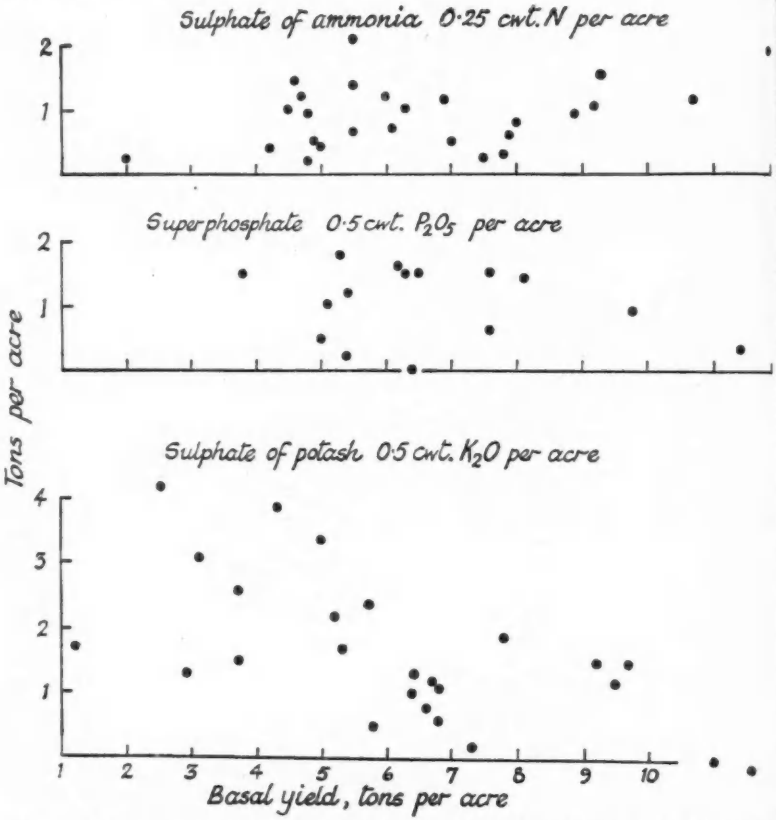
Sulphate of ammonia 0·25 cwt. N per acre
Superphosphate 0·5 cwt. P_2O_5 per acre
Sulphate of potash 0·5 cwt. K_2O per acre
Tons per acre
Basal yield, tons per acre

FIG. 1. Responses to unit dressings plotted against basal yields (Rothamsted). No dung.

The increments vary from year to year, but less than those for the standard dressings of phosphate and of potash (Fig. 1). They show no relation to the initial yield, and they are not affected by farm-yard manure.

Further they were substantially the same in the early years when the land was known to be in poor condition, as in the later years when it was much better; the average calculated increases per 0·25 cwt. nitrogen were:

1925–31	.	.	. 1·12 tons potatoes
1932–40	.	.	. 1·08 „ „

Even as between the original Lawes and Gilbert experiments and our latest set the difference is not great in spite of the wide difference in varieties: their average increment for 4 cwt. sulphate of ammonia was 3·2 tons whilst ours was 2·45 tons potatoes.

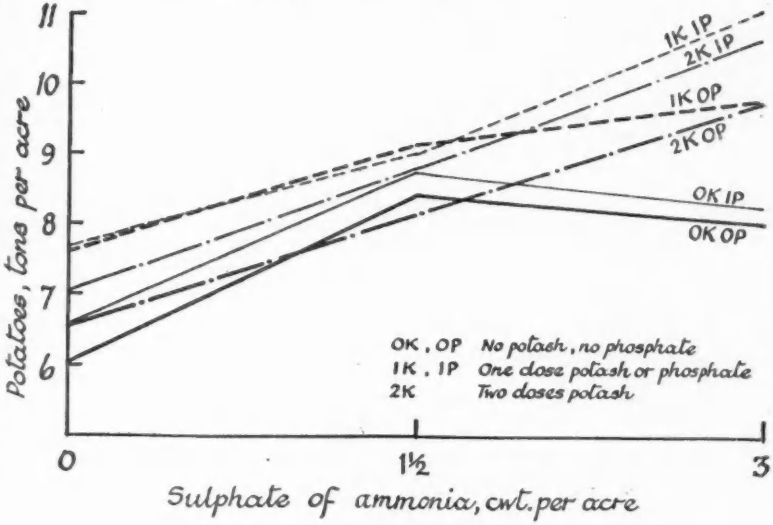

FIG. 2. Effect of fertilizers on yield of potatoes.

TABLE 3. *Effect of Phosphatic and Potassic Fertilizers on the Action of Nitrogenous Fertilizers.* (*Rothamsted*)

		No super. K_2O *cwt. per acre*			*Super.* (0·5 *cwt.* P_2O_5 *per acre*) K_2O *cwt. per acre*		
1928	..	0	0·5	1·0	0	0·5	1·0
Nitrogen	0	6·09	7·62	6·58	6·60	7·67	7·06
cwt.	0·3	8·42	9·15	8·13	8·75	9·03	8·79
per acre	0·6	8·00	9·76	9·74	8·26	11·05	10·63
1931	..	0	0·4	0·8	0	0·4	0·8
Nitrogen	0	10·11	10·79	11·33	11·02	10·69	10·27
cwt.	0·2	11·35	11·23	11·65	11·78	11·65	12·10
per acre	0·4	12·26	11·94	11·97	13·11	12·08	12·87

Action of potassic and phosphatic fertilizers on the effectiveness of nitrogenous fertilizers.—The figures in Table 2 are the means for all plots

receiving the specified nitrogenous dressing, but in poor soil conditions the effectiveness of the nitrogen is enhanced by phosphate and potash. In more fertile conditions phosphate still enhances the effect, though potash does not. The two cases are illustrated in Table 3. The 1928 experiment was on poor soil and the basal yield without fertilizer was only 6 tons per acre: this was raised to 9·7 tons by the addition of sulphate of potash and to 10·6 tons by the further addition of superphosphate, but only at the higher, not at the lower, levels of nitrogenous manuring. This important point is illustrated in Fig. 2: the crop increases for the first dose of nitrogen are much the same for all treatments, but those for the second show a wider spread. The 1931 experiment, on the other hand, was made in much more productive conditions, and although the increment given by the nitrogen is substantially the same as in the earlier experiment, there is no enhancement of the effect by potash though there is by phosphate.

The general effects at Rothamsted are shown in Fig. 3.

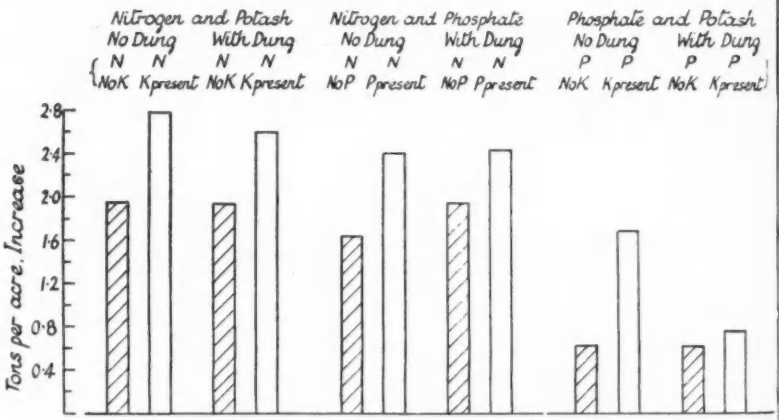

FIG. 3. Action of one fertilizer on the effectiveness of another (Rothamsted).

The average enhancement of the nitrogen effect by potash at Rothamsted has been, in tons per acre:

	Yield *No* N, *no* K	*Increase given by* N, *no* K	K, *no N*	N+K	*Enhancement‡ of nitrogen effect by potash*
No dung*	7·26	1·94	1·04	3·82	0·84
Dung†	8·02	1·93	0·09	2·69	0·67

* 1925–39, 0·7 cwt. N and 1·5 cwt. K_2O per acre; 6 experiments.
† 1926–39, 0·6 cwt. N and 1·5 cwt. K_2O per acre; 9 experiments.
‡ The enhancement is (N+K)−N−K = 3·82−1·94−1·04 = 0·84.

The enhancement by phosphate at Rothamsted has been, in tons per acre:

	Yield No N, *no* P	*Increase given by*			*Enhancement of* N *effect by* P
		N, *no* P	P, *no* N	N+P	
No dung* .	6·68	1·63	0·45	2·85	0·77
With dung† .	7·88	1·94	0·51	2·95	0·50

* 5 experiments: 0·7 cwt. N and 0·7 cwt. P_2O_5 per acre.
† 6 experiments: 0·7 cwt. N and 0·6 cwt. P_2O_5 per acre.

A similar enhancement both by potash and by phosphate is seen at the outside centres; it is more pronounced for potash on heavy than on light soils except in the fens (Table 4).

TABLE 4. *Summary showing Enhancement* of Nitrogen Effect by Potassic and Phosphatic Fertilizers at Outside Centres. Tons per acre*

Potassic Fertilizers

	Mineral soils				*Fen soils*	
All centres:	*Light*	*Medium*	*Silt*	*Heavy*	*Light*	*Heavy*
No dung . .	0·42 (9)	0·10 (3)	−0·12 (4)	1·06 (3)	0·44 (13)	0·04 (9)
Dung . .	−0·38 (2)	0·88 (1)	−0·18 (3)	0·72 (1)	0·02 (6)	0·88 (2)
Experiments showing definite responses to potash:						
No dung .	−0·08 (4)	0·68 (2)	..	1·06 (3)	0·52 (12)	0·08 (1)
Dung . .	..	0·88 (1)	Nil (1)	0·72 (1)	0·34 (3)	0·20 (1)
All centres:		*Phosphatic Fertilizers*				
No dung .	−0·04 (11)	0·54 (6)	0·96 (1)	0·86 (3)	0·36 (9)	0·78 (8)
Dung . .	0·78 (1)	..	0·42 (3)	..	0·10 (4)	2·00 (2)
Experiments showing definite responses to phosphate:						
No dung .	0·44 (4)	0·86 (2)	0·96 (1)	1·20 (2)	0·92 (5)	0·78 (8)
Dung . .	0·78 (1)	..	0·88 (1)	..	0·58 (2)	2·00 (2)

* In the Rothamsted Reports the enhancement is halved and called 'interaction' (see *Roth. Ann. Rept.*, 1936, pp. 170–3); this mode of presentation has advantages from the statistical point of view, but for our present purpose the actual experimental figure is preferable.

The enhancing action of phosphatic fertilizers on the effectiveness of nitrogen is usually rather greater than that of potash except on the heavy soils, where, as at Rothamsted, the effect is reversed.

Action of farm-yard manure on the effectiveness of nitrogenous fertilizers.—Farm-yard manure has practically no action on the effectiveness of sulphate of ammonia at Rothamsted (Table 2). The increments are:

	Without dung	*With dung*
For 2 cwt. sulphate of ammonia per acre . .	1·59	1·74
„ 4 „ „ „ „ . .	2·45	2·37

The same result is obtained also at the outside centres, as shown in Table 6: only on the light soils did any marked difference appear. A typical experiment at the Seale Hayne College in 1927 gave:

No farm-yard manure				*Farm-yard manure*			
No sulph. amm.	*Additional yield for sulph. amm. cwt. per acre*			*No sulph. amm.*	*Additional yield for sulph. amm. cwt. per acre*		
	1	2	3		1	2	3
3·70	1·50	2·52	2·60	5·32	1·36	2·27	2·82

Calculated increase for 0·25 cwt. N 1·73 . . . . . 1·66

At other centres where there was a direct comparison the results were:

	Without dung		*With dung*	
	Yield without sulph. amm.	*Additional yield for sulph. amm.*	*Yield without sulph. amm.*	*Additional yield for sulph. amm.*
6 Northumberland and Durham centres* .	5·77	0·61	8·17	0·49
Light Fen, Wimblington†: 3 years . . .	6·14	0·31	8·68	0·99
5 centres‡ 1940 . .	9·04	0·20	9·72	0·33

* 2 cwt. each sulphate of ammonia and of potash, 4 cwt. superphosphate; 12 tons dung per acre where given.

† *Rothamsted Reports*, 1934, p. 229; 1935, p. 258; 1936, p. 262. 0·5 cwt. N.

‡ 0·6 cwt. N.

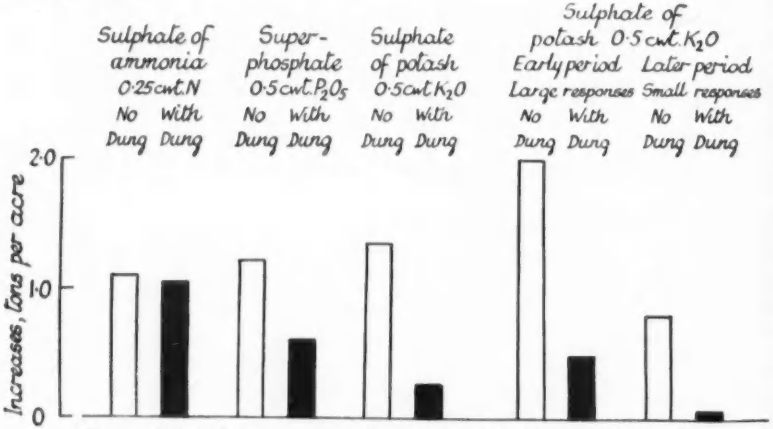

FIG. 4. Effect of dung on the action of artificial fertilizers (Rothamsted). Increases, tons per acre.

We are unable to account for this remarkable result. The effect of a given quantity of sulphate of ammonia is diminished when more sulphate of ammonia is added, but not when dung is added, yet both increase the

supply of nitrogen. Part of the effect may be due to the potash in the farm-yard manure, which as shown in Fig. 3 enhances the effect of the nitrogen, but something more seems to be involved. Whatever the action, it is peculiar to nitrogen, for the farm-yard manure depressed the effect of phosphate and of potash just as additional fertilizer would do (Fig. 4).

Influence of soil type on the effectiveness of nitrogenous fertilizers.—The simplest comparison showing the effect of soil type is that of Rothamsted and Woburn in the 6-course rotation experiment (p. 197), and the results are in tons per acre:

	Basal yield No nitrogen	*Mean increment for 0·25 cwt.* N *per acre*	*Annual variation (S.E. per year)*
Heavy soil (Rothamsted) .	5·79	0·64 ± 0·10	± 0·32
Light soil (Woburn) .	6·1	1·73 ± 0·30	± 1·00

The similarity in basal yields is striking, but it is confirmed in the outside experiments, where if the rich silt and the heavy fen are excluded the effect of soil type on yield is seen to be small (Table 5).

The increment per unit dressing of nitrogen is larger at Woburn than at Rothamsted. In general at other centres the light soils are not more but usually less responsive than the medium and heavy ones.

For annual variation we have figures only for Rothamsted and Woburn,

TABLE 5. *Effect of 0·25 cwt. Nitrogen as Sulphate of Ammonia on Soils of Different Types (1921–40). Yield of potatoes, tons per acre*

	No dung			*Dung*		
	No. of experiments	*Yield No* N	*Calculated increase for 0·25 cwt.* N	*No. of experiments*	*Yield No* N	*Calculated increase for 0·25 cwt.* N
Light . .	34	7·71	0·74	15	8·48	0·32
Medium . .	41	6·62	1·20	9	8·02	0·95
Rich silt* . .	2	12·08	0·52	4	11·02	1·20
Heavy . .	20	7·11	0·76	9	7·60	0·76
Rothamsted .	15	7·07	1·11	14	8·08	1·16
Light fens . .	13	7·19	0·55	7	9·17	0·71
Heavy fens .	8	9·49	1·61	3	8·55	1·30
Totals and means	133	8·18	0·93	61	8·70	0·91

* This soil has been exceptionally heavily manured for many years: potatoes have been taken every third year.

and the light soil shows greater variability in response to nitrogen than the heavy one. This happened also in the continuous experiments on wheat and barley.[1]

The response to nitrogen has but little relation to the basal yield. It

[1] *Fifty Years of Woburn Experiments.* E. J. Russell and J. A. Voelcker. Rothamsted Monographs on Agricultural Science, Longmans & Co.

varies from year to year, but whatever the causes, they do not appear to be the same as those governing the variations of the basal yield (Fig. 1).

The effect of farm-yard manure cannot properly be seen from Table 5 because the numbers of experiments are not the same in the two sections: it is dealt with later. The heavy fen soils and the silt did not respond to dung, though the others did. On none of the soils where the comparison was valid, however, did the farm-yard manure appreciably affect the response to sulphate of ammonia.

The small effect of soil type on basal yield, apart from the heavy fen and the rich silt, shows that no one soil type is markedly better for the growth of potatoes than any other, though the heavy fen soil is actually the most responsive. One important factor, however, does not come into account here. The considerable amount of cultivation necessary for the growth of potatoes which is given as a matter of course in the experiments becomes of primary importance in practice, and hence potato-growing in peace-time is largely restricted to soils easy to cultivate.

In some of the experiments the sulphate of ammonia was given at two different rates. The results were very similar to those at Rothamsted: the first dose gave a substantial increase and the double dose gave a further good, but not a doubled, increase (Table 6), and as in the experiments set out above, the heavy fen soils were the most responsive to both dressings and the light soils were least responsive (Fig. 5).

Other Nitrogenous Compounds

Calcium cyanamide was tested at Rothamsted for several years, but it gave only about 60 per cent. of the response from sulphate of ammonia supplying equal amounts of nitrogen (0·6 cwt.) per acre. The average result of all experiments[1] was:

Number of expts.	*Yield, tons per acre*			*Response to nitrogen in calcium cyanamide when that to sulph. amm. = 100*
		Increase for		
	No nitrogen	*Sulph. amm.*	*Cyanamide*	
6	7·36	1·66	0·97	59

There is therefore no reason why calcium cyanamide should be used for potatoes.

Ammonium bicarbonate.—At one period it appeared probable that at many of the smaller gas-works the bicarbonate could be more conveniently prepared than the sulphate of ammonia. Unfortunately it decomposes readily giving off ammonia and so is liable to loss: it therefore does not give as good returns as the sulphate:

Number of expts.	*Yield, tons per acre*			*Response to nitrogen in bicarbonate when that to sulphate = 100*
		Increase for 0·6 cwt. N as		
	No nitrogen	*Sulphate*	*Bicarbonate*	
9	8·46	1·06	0·61	57

[1] *Rothamsted Ann. Repts.*, 1927, p. 155, and subsequent issues till 1931, p. 192.

Muriate of ammonia.—This salt could have been made on the large scale as an alternative to the sulphate, and experiments with barley suggested that it possessed some superiority. On potatoes, however, it was

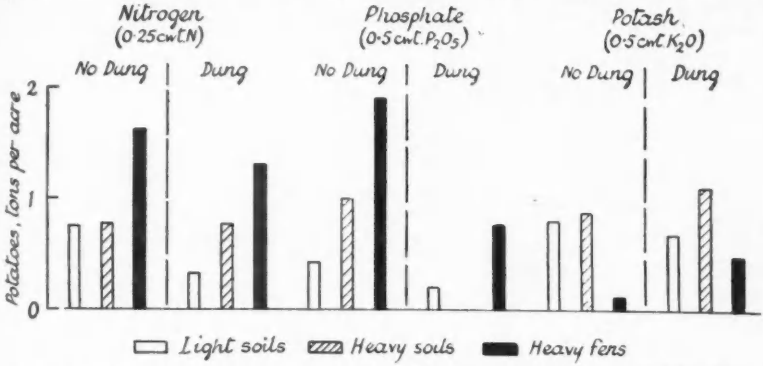

FIG. 5. Fertilizer responses on different soil types. Increases for the standard dressings.

TABLE 6. *Effect of Increasing Dressings of Sulphate of Ammonia on Different Soils*

Soil type	*No. of experiments*	*Yield No N tons per acre*	*Increase for sulph. amm., tons per acre*	
			One dose ($1\frac{1}{2}$–2 cwt. per acre)	*Two doses (3–4 cwt. per acre)*
Light and medium soils				
No dung	11	9·02	0·88	1·41
With dung	7	9·22	0·66	0·76
Rothamsted				
No dung	7	8·00	1·60	2·49
With dung	8	8·13	1·60	2·37
Light fen				
No dung	6	8·18	1·15	1·64
Heavy fen				
No dung	5	8·96	2·21	3·21

less successful because its chlorine[1] is harmful: with a mean dressing of 0·4 cwt. N per acre the results were:

Yield, tons per acre

	No. of experiments	*No nitrogen*	*Increase for*		*Response to nitrogen in muriate when that in sulphate = 100*
			Sulphate	*Muriate*	
Dung	23	8·67	0·96	0·79	82
No dung	17	5·76	1·54	1·31	85

[1] It contains 66 per cent. Cl.

The mean depression per cwt. of Cl is about the same as for muriate of potash. As in that case also the depression is greater in the drier years than in the wetter ones, but there was no marked drought in any of the years of experiment, and we cannot say whether any reversal of the effect would in those conditions be obtained as seems to happen with muriate of potash (v. Part II). In the wet years the reduction of the depression apparently went further than for the muriate of potash, giving a small increase in yield, but as the experiments were all of the old type we cannot be sure that this particular effect is real, though there seems no doubt about the increased harmfulness in the drier seasons:

Yield with sulphate, tons	8·02	9·75	10·69	9·54	9·44
Muriate*: increase (+) or decrease (−) . .	+0·61	+0·23	−0·13	−0·19	−0·30
Rainfall, April–July, inches† . . .	14·3	10·74	10·71	8·73	7·65
Year and no. of centres .	1924 (3)	1922 (6)	1926 (3)	1925 (3)	1923 (3)

* Equal quantities of nitrogen used, except in 1925 and 1926 when equal weights of fertilizer were given.

† At Rothamsted.

Effect of Superphosphate on the Yield of Potatoes

The Rothamsted experiments with superphosphate are summarized in Table 7. The basal yields have varied from 5·1 to 12·9 tons per acre and the increases, calculated to 0·5 cwt. P_2O_5 per acre, from 0·20 to 1·47 tons per acre; the variability in effect is thus greater than in the case of nitrogen. There is a small but not significant tendency for the increases in absence of dung to be higher in years of low basal yield (Fig. 1).

The increments given by superphosphate are increased by the addition of nitrogenous and of potassic fertilizers; this is dealt with on pp. 201 and 212, and it is well shown in the experiments of 1938, the results of which were:

	No Dung				*Dung*			
	No super.		*Increase due to 5 cwt. super.**		*No super.*		*Increase due to 5 cwt. super.*	
Sulphate of ammonia (cwt. N)	Sulph. pot. (cwt. K_2O)		Sulph. pot. (cwt. K_2O)		Sulph. pot. (cwt. K_2O)		Sulph. pot. (cwt. K_2O)	
	0	1·6	0	1·6	0	1·6	0	1·6
0	8·18	9·27	+0·20	+1·56	11·65	11·73	+1·53	+0·82
0·4	8·15	9·80	+1·09	+3·34	13·78	12·77	−0·05	+1·77
0·8	11·87	11·42	−2·51	+3·28	13·99	13·50	+0·58	+2·44

* 0·8 cwt. P_2O_5

Action of farm-yard manure on the effectiveness of superphosphate.—In striking contrast with the results on p. 203 farm-yard manure depresses the effectiveness of superphosphate notwithstanding that much of its action is determined by its nitrogen and its potash. The depression appears on all types of soil (Table 9) and its actual amount is shown in Table 8,

which summarizes the experiments designed to measure it. At Rothamsted 15 tons of dung per acre supplying 0·9 cwt. P_2O_5 halved the effect of 0·8 cwt. P_2O_5 as superphosphate; at Tunstall also the effect was halved, but the action was more variable at the other centres (Fig. 4).

TABLE 7. *Increases in Yield given by Superphosphate (Rothamsted). Calculated Values for 0·5 cwt. P_2O_5 per acre; tons per acre*

	1928	*1929*	*1930*	*1931*	*1933*	*1937*	*1938*	*1939*	*Mean*
No dung									
Yield without phosphate .	..	..	..	11·40	5·01	5·40	9·78	6·29	7·58
Increase for 0·5 cwt. P_2O_5 .	..	..	..	0·33	0·49	1·19	0·90	1·47	0·88
Dung									
Yield without phosphate .	8·17	5·12	8·57	..	..	8·20	12·90	10·77	8·96
Increase for 0·5 cwt. P_2O_5 .	0·49	0·58	0·80	..	..	0·66	0·93	0·20	0·61

*Woburn**	*1927*	*1928*	*1929*	*1930*	*Mean*
Yield without phosphate .	4·06	12·25	5·05	11·11	8·12
Increase for 0·5 cwt. P_2O_5 .	Nil	1·36	−0·02	−0·22	0·28

* Dung was given in each year except 1929.

Six-course rotation: no dung: average 11 years 1930–40, tons per acre

	Yield without phosphate	*Additional yield for P_2O_5 cwt. per acre*			
		0·15	0·30	0·45	0·60
Rothamsted . .	6·47	−0·28	0·45	0·67	0·69
Woburn . . .	7·31	0·41	0·88	0·83	0·57

(0·15 cwt. P_2O_5 = 1 cwt. superphosphate)

Action of soil type on the effectiveness of superphosphate.—The response to phosphate is greater on the heavy soil at Rothamsted than on the light soil at Woburn, and this appears to hold generally (Table 9). On the other hand, the annual variation is about the same at the two centres, but whereas at Woburn it shows no relation to the basal yield there is an indication that at Rothamsted the phosphate has been more effective in the less productive seasons (Fig. 1).

	Basal yield No phosphate	*Mean increment for 0·5 cwt. P_2O_5 per acre*	*Annual variation (S.E. per year)*
Heavy soil (Rothamsted) .	6·47	0·84±0·33	±1·10
Light soil (Woburn) . .	7·31	0·57±0·33	±1·08

The heavy fen soils are the most responsive: on these an increase of nearly 2 tons per acre was obtained for a dressing of 0·5 cwt. P_2O_5. Heavy

mineral soils gave about half this increase, but light mineral soils gave less (Table 9).

This varying response on different soil types does not depend on the general fertility of the land, as shown by the mean yield, for some of the highest responses are obtained on soils so rich that even without added phosphate they still give high yields per acre: this is in sharp contradistinction to potash, which has but little effect in more productive conditions.

TABLE 8. *Effect of Superphosphate in Presence and Absence of Dung. Potatoes, tons per acre*

		No dung		*With dung*		*Manure per acre*	
Year	*Centre*	*Yield without phosphate*	*Increase given by phosphate*	*Yield without phosphate*	*Increase given by phosphate*	P_2O_5 *cwt.*	*Dung tons*
1937	Rothamsted	5·40	1·52	8·20	0·85	0·8	15
1938	Rothamsted	9·78	1·26	12·90	1·19	0·8	15
1939	Rothamsted	6·29	1·88	10·77	0·26	0·8	15
	Mean*	7·16	1·55	10·62	0·77	0·8	15
1935	Wimblington	5·66	0·49	8·16	0·45	1·0	8
1936	Wimblington	7·64	0·03	9·24	−0·80	1·0	8
	Mean	6·65	0·26	8·70	−0·18	1·0	8
1937	Tunstall	5·79	0·64	6·31	0·36	1·0	10
1940	Cudworth	6·14	0·79	7·66	0·15	0·64	10

* For standard dressing of 0·5 cwt. P_2O_5 the increases are: no dung 1·19, dung 0·60.

TABLE 9. *Response to Superphosphate on Soils of Different Types*

Increase yield of potatoes (tons per acre) given by 0·5 cwt. P_2O_5 per acre

	No dung			*With dung*		
Soil type	*No. of experiments*	*Yield without phosphate*	*Calculated increase given by phosphate*	*No. of experiments*	*Yield without phosphate*	*Calculated increase given by phosphate*
Light	18	7·85	0·42	7	8·35	0·20
Medium	9	4·38	0·79	3	13·21	0·96
Rich silt	2	12·36	0·82	8	13·14	0·45
Heavy	5	6·22	1·03	..	..	..
Rothamsted	5	7·22	0·88	6	8·96	0·61
Light fen	10	6·76	0·78	6	9·05	0·15
Heavy fen	9	9·51	1·90	2	8·05	0·76
Totals and means	58	7·76	0·95	32	10·13	0·52

A double dressing of superphosphate gave a larger yield than a single one though not so large proportionately as was given by nitrogen. The heavy fen soil gave the largest increases both for the single and the

double dressings and at Owmby (Lincolnshire Cliff) there was no increase for either. On the light fen the effect of superphosphate was much reduced by dung, but nevertheless the double dressing gave a larger return than the single one (Table 10).

TABLE 10. *Effect of Single and Double Dressings of Superphosphate on Different Soils*

	Yield No P	*Increase for super.*	
		4–5 cwt.	*8–10 cwt.*
Wisbech silt with and without dung (9 years) . .	12·99	0·64	0·74
Owmby, Lincs., cliff land with and without dung (4 years)	8·50	−0·02	−0·12
Light fenland			
No dung (6) . . .	7·48	1·28	1·61
With dung (4) . .	9·23	0·29	0·51
Heavy fenland			
No dung (8) . . .	9·23	2·40	3·40

(The numbers in brackets are the numbers of experiments)

Effect of Gafsa phosphate.—Gafsa phosphate is compared with superphosphate in the four-course rotation experiment (p. 197), but it always comes out inferior.

	Year of application	*Years after application*			
		1st	*2nd*	*3rd*	*4th*
Superphosphate .	5·57	3·96	4·16	3·88	4·03
Gafsa phosphate .	3·12	2·74	3·48	3·40	2·94

Dressings of 1·8 cwt. sulphate of ammonia and 1·2 cwt. muriate of potash per acre were given also, but no organic manure.

Effect of Potassic Fertilizers

THE marked effect of potassic fertilizers on potatoes was demonstrated as early as 1870 by Augustus Voelcker in a series of farm experiments made in different parts of England,[1] but was unfortunately not tested in the early Rothamsted experiments.

One of the most striking results of the modern experiments both at Rothamsted and the outside centres has been the variability of the effect of potassic fertilizers according to the conditions. The increments in the Rothamsted experiments of 1925–31 are set out in Table 11; they fall more rapidly with the second and third doses than in the case of nitrogen. Taking the experiments as a whole the response to potash is more variable than that to phosphate or nitrogen (Fig. 1, p. 200), but a good deal of this is due to soil conditions as shown later. In the six-course rotation where these are eliminated the annual variation is no greater than for phosphate, but the responses are related to the basal yield, being higher in the bad seasons than the good ones. The experiment has not

[1] *J. Roy. Agric. Sci. Eng.*, 1870, **6**, 392.

TABLE 11. *Effect of Increasing Doses of Sulphate of Potash on Yield of Potatoes (Rothamsted). Tons per acre*

Year*	Yield without potash	Additional yield for sulph. pot.			K_2O in smallest dose cwt.
		One dose	Two doses	Three doses	
1925	5·73	..	3·14	4·08	1·0
1926	8·62	1·00	1·16	1·28	0·5
1927	6·92	..	0·46	0·43	1·0
1928	7·69	1·36	0·80	..	0·5
1929	5·21	0·14	0·31	..	0·5
1930	8·40	0·94	1·15	..	0·4
1931	11·60	−0·26	0·43	..	0·4

Six-course rotation: no dung: average 11 years 1930–40.

	Yield without potash	Additional yield for K_2O, cwt. per acre			
		0·25	0·50	0·75	1·00
Rothamsted .	4·99	1·58	1·99	2·15	2·63
Woburn . .	7·68	0·0	0·78	0·63	0·73

(0·50 cwt. K_2O = 1 cwt. KCl)

* *Rothamsted Ann. Repts.*, 1925, p. 139; 1926, p. 140; 1927, p. 141; 1928, p. 143; 1929, p. 99; 1930, p. 145; 1931, p. 154.

continued long enough to show how the responses are affected by the various weather conditions. In the shifting experiments, which are more numerous, the effects of soil conditions override other factors and no relation can be traced with hours of sunshine or of rainfall.[1]

Action of nitrogenous and phosphatic fertilizers on the effectiveness of potassic fertilizers.—The enhancement of the potash effect by sulphate of ammonia is shown on p. 202; superphosphate also has a similar but greater effect in absence of dung, especially on the light fen, and even on the silts and light soils where sulphate of ammonia caused no enhancement; in presence of dung, however, superphosphate is without effect on the action of the potash (Table 12).

TABLE 12. *Effect of Superphosphate on the Effectiveness of Potassic Fertilizers. Tons per acre*

	Rothamsted	Mineral soils			Fen soils		
		Heavy	Medium	Light	Silt	Heavy	Light
All centres:							
No dung	1·07 (5)	0·06 (2)	−0·24 (4)	0·12 (10)	0·80 (2)	−0·66 (7)	1·04 (10)
Dung .	0·14 (5)	..	..	−0·74 (1)	−0·10 (3)	−0·48 (2)	0·48 (4)
Experiments showing definite responses to potash:							
No dung	1·50 (4)	2·42 (1)	0·96 (1)	0·48 (6)	1·14 (1)	0·30 (2)	1·06 (7)
Dung .	−0·14 (2)	..	..	..	−0·42 (1)	−1·12 (1)	0·24 (1)

[1] In the earlier years of the experiments there seemed to be indications of increased effectiveness of potassic fertilizers in sunless seasons, but in the fuller series this does not appear, though whether this is the result of the change described on p. 214 cannot at present be determined.

The details of the Rothamsted results are:

	Yield	*Increase given by*			*Enhancement of P-effect by* K
	No P *No* K	P, *no* K	K, *no* P	P+K	
No dung* . .	7·66	0·62	0·60	2·29	1·07
With dung† . .	9·22	0·62	0·03	0·79	0·14

* 5 experiments. 0·8 cwt. P_2O_5 and 1·3 cwt. K_2O per acre.
† 4 experiments. 0·7 cwt. P_2O_5 and 1·4 cwt. K_2O per acre.

Depressing action of farm-yard manure.—In sharp contrast with sulphate of ammonia, the effectiveness of potassic fertilizer, like that of superphosphate, is greatly reduced by farm-yard manure. All experiments show this: the average result of all the modern replicated experiments at Rothamsted and outside centres, where dung had been one of the experimental treatments, was:

	No dung	*Dung*	*Increase for dung*
No potash . . .	8·08	10·32	2·24
K_2O, 0·5 cwt. per acre .	9·16	10·53	1·37
Increase for potash . .	1·08	0·21	
Depression of potash effect by dung . . .	0·87		Depression of dung-effect by potash = 0·87

The nitrogen and phosphate present in the dung might have been expected to enhance the effect of the potassic fertilizer, but in spite of this the total action of the dung is very depressing. A probable explanation is the large amount of K_2O present in the dung, a 15-ton dressing supplying some 225 lb. But this applies also to the nitrogen, and yet in that case there is no depression.

The depression is of course mutual, and it is equally true to say that potassic fertilizers depress the action of dung as to say that dung depresses the action of potash.

Effect of soil conditions on the action of potassic fertilizers.—The soil conditions profoundly affect the action of potassic fertilizers on potatoes: even on the same farm and in the same season different fields give different responses. At Rothamsted the calculated responses to 0·5 cwt. K_2O were, in tons per acre:

	1939			*1940*		
	Gt. Knott	*Long Hoos II*	*Long Hoos*	*West Barn*	*Gt. Harpenden*	*Long Hoos*
No potash	6·85	6·40	5·25	7·84	6·76	5·39
Increase for potash	0·63	1·05	2·20	1·91	1·10	1·71

It commonly happens that a soil in poor condition responds better to potash than an otherwise similar soil in good condition. The first of the Rothamsted experiments were made on poor fields only recently

taken over; they gave poor basal yields but good responses. As the land was improved, however, the basal yields went up but the responses went down:

		No dung		*Dung*	
*Period**	*No. of seasons*	*Yield without potash*	*Calculated increase for 0·5 cwt.* K_2O	*Yield without potash*	*Calculated increase for 0·5 cwt.* K_2O
1921–4 .	4	5·01	2·00	8·10	0·49
1932–40 .	5	7·83	0·81	10·73	0·07
Mean .	9	6·58	1·34	9·56	0·26

* The 1921–4 experiments were of the old replicated type; the later ones in 1931–2 and 1937–40 were of modern factorial type.

At the outside centres very productive soils capable of yielding 10 tons or more of potatoes without additional potash showed little benefit from the use of potassic fertilizer. At three of the centres potatoes heavily manured with dung and artificials had long formed part of the cropping scheme; at all of them the effect of potassic fertilizer has been small.

Soil	*Location*	*No. of experiments*	*Mean yield tons per acre*	*Mean increase for 0·5 cwt.* K_2O
Silts . .	Wisbech area	5	11·18	0·18
Clay fen . .	Littleport	10	10·18	0·19
Fertile light soil	Sutton Bonnington	6	9·2	0·16

Effect of soil type.—The marked variation in effect of potassic fertilizers with the soil conditions makes it difficult to generalize about the influence of soil type. In the six-course rotation the response to potash on the light soil at Woburn is much less than on the heavy soil at Rothamsted: it is also less variable and quite differently related to the initial yield:

	Basal yield No potash	*Mean increment per 0·5 cwt.* K_2O *per acre*	*Annual variation (S.E. per year)*
Heavy soil (Rothamsted) .	4·99	1·70±0·32	±1·06
Light soil (Woburn) .	7·68	0·61±0·18	±0·61

Reference to Table 13 shows that the Rothamsted response is unusually high while that at Woburn is not markedly different from what is obtained on other light mineral soils. But there is no evidence at these particular centres for the common statement that light soils respond much better than heavy ones to potash excepting only on the light and heavy fen. The latter is the least responsive of all soils examined; the other relatively unresponsive is the silt: both are obviously in high condition as shown by the high initial yield, and in these circumstances as we have already seen potash does not act well.

TABLE 13. *Mean Effect of 0·5 cwt. K_2O on Yield of Potatoes on Soils of Different Types in Presence and Absence of Dung*

	No dung			*Dung*		
	No. of experiments	*Yield without potash*	*Calculated increase for 0·5 cwt. K_2O*	*No. of experiments*	*Yield without potash*	*Calculated increase for 0·5 cwt. K_2O*
Mineral soils:						
Light	22	7·25	0·80	16	9·11	0·68
Medium	15	7·81	0·98	8	8·88	0·90
Rich silt	1	12·87	0·34	3	12·07	0·26
Heavy	8	6·81	0·89	11	7·33	1·11
Rothamsted	15	5·92	1·76	15	9·33	0·45
Fen soils:						
Light	15	6·67	1·73	7	9·08	0·79
Heavy	8	10·63	0·12	2	8·35	0·48
Totals and means	84	8·28	0·95	62	9·18	0·67
Weighted mean	..	..	1·11	..	..	0·71

Cross comparisons between effects in presence and absence of dung cannot be made except at Rothamsted, as different centres and years are involved.

As at Rothamsted, the second dose of potassic fertilizer is much less effective than the first and only on the light fen soils and at Rothamsted without dung has it been economically advantageous. The heavy fen and the silt have been very unresponsive (Table 14).

TABLE 14. *Effect of Increasing Dressings of Sulphate or Muriate of Potash*

Soil type	*No. of experiments*	*Yield No K*	*Increase for sulphate or muriate of potash*			
			1–1½	*1½–2*	*2–3*	*3–4 cwt.*
Light and medium:						
No dung	12	9·12	+0·63	..	+0·72	..
With dung	4	8·26	+0·40	..	+0·60	..
Rothamsted:						
No dung	2	8·36	..	+1·64	..	+2·12
With dung	4	7·48	+0·81	+0·87	..	..
Light fen:						
No dung	5	6·23	..	+2·49	..	+3·17
Heavy fen:						
No dung	6	10·55	..	+0·19	..	+0·29
Silts:						
With and without dung	4	12·04	..	+0·26	..	+0·24

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THE ROTHAMSTED EXPERIMENTS ON THE MANURING OF POTATOES

PART II. EFFECTS OF INORGANIC AND ORGANIC MANURES ON THE YIELD OF POTATOES

SIR E. J. RUSSELL AND H. V. GARNER

(Rothamsted Experimental Station, Harpenden, England)

Effect of Magnesium Salts

IN view of the marked effect of potassium on the growth of potatoes, experiments were made to ascertain whether magnesium, an essential constituent of chlorophyll, would also increase their growth. The question gained additional practical importance from the fact, which came into prominence after the 1914–18 war, that the German potash deposits contain magnesium salts while the Alsatian deposits do not. The salt used was the sulphate so as to avoid complications that might arise from the presence of a chloride.

The early experiments (1921–3) indicated that magnesium sulphate was usually without influence on the growth of potatoes, but might on occasion affect the yield, in some cases beneficially, in others adversely. At Rothamsted an increase was only once recorded; it was on the plots without farm-yard manure but was of doubtful significance. At a few of the outside centres there were marked effects, the most striking being at Blaydon, Durham, where on a light sandy soil the magnesium sulphate improved the size and colour of the foliage.[1] At Newton Abbot (Seale Hayne College) and at Chartley Park on the Bunter Sandstone increases were recorded, but the design of the experiment did not allow the difficulty of soil heterogeneity to be overcome. In a few experiments the magnesium sulphate depressed the yield; in general, however, it had no effect.

The later experiments on modern lines gave very similar results (Table 1). In most cases the magnesium sulphate had no effect. Occasionally, however, it increased the yield, e.g. in 1937, on Bunter Sandstone (p. 218) as in the earlier set, and on a granitic soil; but similar soils gave no increase in 1938, indeed there were two decreases in that season. So far, it has not been possible to account for either the increases or the depressions, but an investigation on the Bunter Sandstone might be fruitful.

Both in the Rothamsted experiments and those of Dr. Cowie sulphate of potash had in most cases given marked increases in yield even where sulphate of magnesium gave none. This result is difficult to understand, as it is in striking contrast with that obtained on Broadbalk Field where sulphate of magnesia was for many years as effective as sulphate of potash and markedly increased the quantity of potassium taken up by the wheat plant, presumably because it displaced potassium from the

[1] *Rothamsted Ann. Rept.*, 1922, p. 19.

soil by a base-exchange process. It is possible that magnesium, while essential in small quantities, may in larger amounts be sufficiently harmful to the potato plant to offset as a rule the benefit of any potassium liberated from the soil.

TABLE 1. *Effect of Sulphate of Magnesium on Yield of Potatoes per acre: Rothamsted and Outside Centres*

No. of expts.	*Yield No* Mg *tons*	*Increase for* Mg *tons*	*Quantity of* $MgSO_4$ *applied lb.*	*Increase for sulph. of pot., tons*	*Quantity of* K_2O *applied, cwt.*
	No farm-yard manure				
Single plots (4) . .	8·22	−0·39	108	+1·67	1·0
Old-style replicated (5)	8·47	+0·36	172	+2·86	1·0
Modern replicated (Tunstall) (1) . .	13·05	+0·21	214	+0·76	1·5
	..	±0·41	..	±0·77	..
	Farm-yard manure given				
Single plots (3) . .	10·04	+0·12	101	+1·41	0·9
Old-style replicated (7)	9·20	+0·13	113	+1·05	0·9
Modern replicated (Woburn) (1) . .	10·90	+0·20	86	+0·10	0·6
	..	±0·28	..	±0·28	..

The earlier experiments include two increased yields by magnesia and one depression which may be significant.

For comparison we have Dr. Cowie's permission to quote his very full set.

Year	*No. of centres*	*Mean yield*	*Increase for* 0·3 *cwt.* MgO	0·6 *cwt.* MgO	0·7 *cwt.* K_2O	1·4 *cwt.* K_2O
1937	24	9·05	+0·07	+0·11	+1·80	+2·17
1938	23	8·57	..	+0·00	..	+2·54

In 1937 there were two increased yields, one on the Bunter Sandstone and the other on a granitic soil, and in 1938 two decreases and one increase, all of which were significant.

Effect of Sodium Salts

One experiment only with sodium chloride has so far been made: it was on newly ploughed grass-land at Rothamsted in 1940. Potash clearly increased the yield, but salt did not, although it did no harm:

	Mean	*Responses to mur. pot.*	*Salt*
Total produce, tons per acre .	9·02	2·37	0·04
Percentage ware . . .	86·0	5·6	1·2

Effect of Chloride on the Growth of Potatoes

The potato crop differs from several of the others that have been examined, and in particular from sugar-beet, in that the chloride ion is definitely harmful under ordinary conditions. This was tested in several ways: the muriates of ammonia and of potash were used instead of the sulphate; and 'potash salts' containing increasing quantities of sodium and magnesium chlorides (Table 2).

TABLE 2. *Reduction of Yield (tons per acre) by Chlorides: Regression of Yield on Quantity of Chlorine supplied*

	No dung		*Dung*	
Series	*No. of experiments*	*Mean reduction of yield per cwt.* Cl	*No. of experiments*	*Mean reduction per cwt.* Cl
Old single-plot .	9	0·17	6	0·21
Old replicated .	13	0·27	27	0·33
Modern factorial	4	0·19	7	0·24

Mean depression in all experiments with and without dung = 0·27 tons.

The chloride depressed the yield in 54 out of 66 experiments, the average reduction being about 5 cwt. potatoes per cwt. chlorine. The depression seemed to be rather more pronounced on light than on heavy soils and greater in the north than at Rothamsted:

	Light soils	*Heavy soils*	*Northern centres**	*Rothamsted*
Depression per cwt. Cl .	0·38	0·21	0·38	0·13 *tons*
No. of experiments .	21	22	13	10

* Heavy soils only so as to eliminate soil effect. The period was the same at both groups of centres, viz. 1921–6.

It did not, however, seem to be affected either by nitrogen, potash, or farm-yard manure. The mean depression caused by 1 cwt. Cl in muriate of ammonia was 0·2 ton per acre and that by the same quantity of Cl in muriate of potash was 0·27 ton per acre. The amount of the depression seems to depend on the rainfall: it was least in the wet season and greatest in the moderately dry ones, but lower in the years of exceptional drought both at Rothamsted and at the northern centres (Table 3).

The data are insufficient to allow of positive conclusions, but assuming the result is true it suggests that the chloride ion has two effects on the potato crop: a harmful one shown in all years, which is reduced by high rainfall presumably because the chloride is washed out of the soil; and a beneficial one shown only in very dry conditions.

TABLE 3. *Depression caused by Chloride in Wet and in Dry Seasons*

Rothamsted			*Durham centres*			
					Mean depression	
Years	*Mean rainfall inches Jan.–Sept.*	*Mean depression tons per cwt. Cl*	*Years*	*Mean rainfall Jan.–Sept.*	*All soils*	*Heavy soils*
1921, 1929	10·8	(4) 0·07	1921, 1923	18·8	(5) 0·18	(2) 0·29
1923, 1926, 1930, 1931	20·3	(7) 0·36	1922, 1925, 1926	22·1	(21) 0·41	(10) 0·41
1925	22·2	(1) 0·18	1924	25·0	(3) 0·33	(1) 0·28
1922, 1924, 1927	25·9	(6) 0·03				

Comparison of Different Potassic Fertilizers

The results in the preceding pages explain and justify the potato-grower's preference for sulphate of potash over other salts. They also explain why the muriate comes second: it is usually cheaper and the depression caused by a 2 cwt. dressing as compared with the return given by the sulphate is of the order of 5 cwt. potatoes per acre, which could not be detected either by observation or by ordinary weighing; indeed we cannot be sure that it is always caused. But for the other potassic fertilizers the depression is clearer: the results of 53 experiments in different parts of the country showed the following response to potassic fertilizers, when the mean response to potash[1] = 100:

	Rothamsted and Woburn			*Other centres*		
	Sulph. pot.	*Mur. pot.*	*Potash salt 30%*	*Sulph. pot.*	*Mur. pot.*	*Kainit*
With dung:						
Cl, cwt. per acre	None	0·96	1·63	None	0·96	3·00
Relative yields .	110	115	76	129	114	57
No dung:						
Cl, cwt. per acre	None	0·78	1·34	None	1·01	3·10
Relative yields .	110	93	98	111	109	80

The Mode of Applying the Artificial Fertilizers

The artificial fertilizers acted better when put into the bouts than if spread broadcast over the field:[2]

[1] The numbers of experiments were:

	With dung	*No dung*
Rothamsted and Woburn .	4	3
Other centres . . .	27	19

[2] *Rothamsted Ann. Rept.* 1935, p. 180. The unmanured plot gave 3·9 tons per acre; sulphate of ammonia without dung or potash and phosphate gave no increase.

	Phosphate and potash only		*Phosphate, potash, and sulph. amm.*	
	Broadcast	*In bouts*	*Broadcast*	*In bouts*
No farm-yard manure .	5·36	5·75	7·26	9·00
Farm-yard manure. .	6·78	7·42	7·91	10·41

The 1940 experiment gave similar results, but the differences were smaller.[1]

Effect of condition of fertilizers.—In recent years granulated mixed fertilizers have been introduced which are easier to handle than the ordinary material and free from dust so that they can be drilled even on a windy day without loss. Experiments made at three centres on good potato farms show that the granular gave slightly higher yields than the ordinary material, but the difference was not significant (Table 4).

TABLE 4. *Comparison of Granular and Ordinary Fertilizers*

Centre	*Soil*	*Yield: no artificials*	*Yield with fertilizer**			
			Ordinary	*Granular*	*Difference*	*S.E.*
Wryde, March	Heavy loam	8·77	12·32	12·74	0·42	±0·354
Benwick, March	Good fen	12·02	15·01	15·30	0·29	±0·409
Feltwell, Brandon	Light fen	8·69	10·99	11·00	0·01	±0·727

* Means of 6, 12, and 18 cwt. dressings per acre. No dung used.

Effect of Farm-yard Manure on the Growth of Potatoes

Increase due to farm-yard manure: Value of its nitrogen.—The increase due to a dressing of 15 tons farm-yard manure applied in the bouts has varied round a mean of 2·3 tons per acre,[2] this being about the increase produced by 0·7 cwt. N or 3½ cwt. sulphate of ammonia. Since the farm-yard manure contained some 0·6 per cent. N, i.e. 1·8 cwt., its nitrogen has about 40 per cent. of the value of that in sulphate of ammonia; this is comparable with the value (50 per cent.) obtained in the Broadbalk wheat experiments for similar quantities of farm-yard manure and sulphate of ammonia.

Reference has already been made in Part I to the remarkable fact that farm-yard manure in spite of its nitrogen-content does not depress the action of the nitrogen in sulphate of ammonia, although it does depress the action of phosphatic and potassic fertilizers. This can equally be stated in the converse form: that sulphate of ammonia has no action on the effectiveness of farm-yard manure, but both potassic and phosphatic

[1] This was combined with a cultivation experiment. Intensive cultivation depressed the yield by 0·66 ton per acre.

[2] Eleven seasons: the range of increase has been from 1·1 to 3·7 tons.

fertilizers reduce it. This is well illustrated in the 1937[1] experiment at Rothamsted:

Yields of Potatoes, tons per acre

	Sulph. amm. *cwt.* N			*Super.* *cwt.* P_2O_5		*Sulph. pot.* *cwt.* K_2O	
	0	*0·4*	*0·8*	*0*	*0·8*	*0*	*1·6*
Dung . .	7·84	9·92	11·06	9·33	9·88	9·42	9·79
No dung .	4·59	6·44	7·46	5·40	6·92	5·79	6·52
Gain due to dung . .	3·25	3·48	3·60	3·93	2·96	3·63	3·27

The mode of application.—If the manure is spread over the whole field it makes little difference whether this is done in autumn or in spring. The manure must, however, be quickly ploughed under or it rapidly loses value. But it is much more effective to apply the manure in the bouts (Table 5), just before planting the potatoes.

TABLE 5. *Effect of Time and Manner of Application of Dung. Tons of Potatoes per acre**

1934	*Dung spread over land and ploughed under*					
	In autumn			*In spring*		
Sulphate of ammonia, cwt. per acre . .	0	2	4	0	2	4
No dung . . .	..	..	..	9·28	10·06	10·85
Fresh dung . . .	10·47	12·88	13·41	10·66	13·00	13·20
Rotted dung . .	11·54	12·56	12·88	10·88	12·77	12·74
Increase due to farm-yard manure . . .	1·72	2·66	2·30	1·49	2·83	2·12

	Sulph. amm.	*No dung*	*Dung: 15 tons per acre*			
			Ploughed in	*In bouts*	*Increase over no dung*	*Increase due to dung in bouts over dung ploughed in*
1935 . .	..	..	7·15	8·06	3·4†	0·91
	..	..	..	..	1·3‡	..
1936 . .	0	4·83	6·19	7·92	3·09	1·73
	2	6·13	6·49	8·10	1·97	1·61
1937 . .	0	4·96	6·02	7·66	2·70	1·64
	2	6·65	7·72	9·76	3·11	2·04
	4	7·73	9·74	11·52	3·79	1·78

* *Rothamsted Ann. Repts.*, 1934, p. 182; 1935, p. 180; 1936, p. 213; 1937, p. 156.
† is mean of all experiments in absence of potash and phosphate, and ‡ is mean when they are present.

[1] *Ann. Rept.* 1937, p. 156. Fifteen tons dung per acre applied in the bouts.

	Increase due to sulph. amm.		
	1936	*1937*	
Sulph. amm. cwt.	2	2	4
No dung . . .	1·30	1·69	2·77
Dung in bouts . .	0·18	2·10	3·86

Condition of the dung: fresh and rotted compared.—In a series of experiments lasting three years no difference could be found in effectiveness between fresh and rotted dung. The freshly made dung was given at a standard rate of 15 tons per acre; the rotted dung had been made from equal quantities of similar materials but during rotting had lost one-third of its weight so that the actual dressing was about 10 tons per acre. The rotted dung was richer in N, P, and K than the fresh dung, but the rotting had been of no advantage; on the other hand it had not reduced its effectiveness (Tables 5 and 7).

Possible substitutes for farm-yard manure: the effect of other organic substances.—In view of the marked benefit of farm-yard manure and the difficulties of obtaining sufficient supplies even for the pre-war acreage of potatoes, a series of experiments was begun with possible alternative sources of organic manure.

Straw.—Straw is the most readily obtainable organic material on the farm and its effect has been tested in two ways: (1) chopped and ploughed in at the rate of 2 tons per acre during January; (2) used in proportions heavier than usual for the making of the dung.

The ploughing in of the straw was not a success and usually caused a small decrease in crop (Table 6).

TABLE 6. *Effect of Straw ploughed in on Yield of Potatoes. Tons per acre**

	No dung			*Dung ploughed in*		*Dung in bouts*	
	Sulph. amm. cwt.	*No straw*	*Increase given by straw*	*No straw*	*Increase given by straw*	*No straw*	*Increase given by straw*
1936 . .	0	4·83	−0·77	6·19	−0·25	7·92	−0·39
	2	6·13	−0·32	6·49	+0·70	8·10	+1·67
1937 . .	0	4·96	−0·75	6·02	−0·36	7·66	+0·36
	2	6·65	−0·43	7·72	−0·34	9·76	+0·31
	4	7·73	−0·55	9·74	−0·38	11·52	−0·92
Mean effect of straw . .	..	..	−0·56	..	−0·13	..	+0·20

* *Rothamsted Ann. Repts.*, 1936, p. 213; 1937, p. 156.

The depression was reduced by dung, and, in absence of dung though not always in its presence, by sulphate of ammonia. The dung had residual effects on the succeeding crops, but the straw had not. The direct addition of straw to the land therefore does not seem promising.

The use of larger quantities of straw for the making of the dung was

also ineffective. Two proportions were tested: a 50 per cent. increase in 1938, and 100 per cent. increase in 1939 and 1940. The additional straw did not affect the composition of the final manure as much as might have been expected: the strawy manure was drier than the normal but contained approximately the same percentages of N, P_2O_5, and K_2O, and after rotting even the nitrogen in the organic matter was approximately the same.[1] But the extra straw contributed nothing to the value of the manure and so far as these experiments go there is nothing to encourage the hope that potato-growers could expand their supplies of farm-yard manure by using more straw in its preparation (Table 7).

TABLE 7. *Comparison of Fresh and Rotted Manure: Effect of Increasing the Amount of Straw on Yield of Potatoes. Tons per acre*

	1938		*1939*		*1940*			
	Normal dung	*Effect of adding more straw*	*Normal dung*	*Effect of adding more straw*	*Normal dung*		*Effect of adding more straw*	
					(*a*)	(*b*)	(*a*)	(*b*)
Fresh dung .	13·55	−0·20	11·14	−0·25	8·15	8·90	0·22	0·31
Rotted dung	13·59	−0·11	10·60	0·36	8·77	9·14	−0·16	0·35
No dung .	..	..	7·23		7·52			

(*a*) Single dressing. (*b*) Double dressing.

Composted straw was inferior to dung (see below).

Residual effects of dung and straw.—A four-course rotation was set up in 1930 to compare the direct and residual effects of dung, composted straw, and straw ploughed in with artificials. The dung was superior to the composted straw in the year of application and in the first year after, but there was no evidence that either of them produced any effect in the later years. Artificials supplying the same amounts of nutrients as the farm-yard manure, but spread over the rotation, gave the best results so long as the phosphate was given as superphosphate. In these experiments the yields have been low for some reason that is not at all clear[2] (Table 8).

TABLE 8. *Percentages of* N, P_2O_5, *and* K_2O *in the Dung used*

	1938				*1940*			
	Normal		*Strawy*		*Normal*		*Strawy*	
	Fresh	*Rotted*	*Fresh*	*Rotted*	*Fresh*	*Rotted*	*Fresh*	*Rotted*
N	0·66	0·75	0·64	0·74	0·62	0·78	0·69	0·93
P_2O_5	0·28	0·37	0·24	0·39	0·27	0·35	0·29	0·42
K_2O	0·82	0·94	0·74	1·06	..	..	..	..
N in organic matter			..	..	3·7	3·9	2·7	4·0

[1] *Rothamsted Ann. Repts.*, 1930, p. 125; 1932, p. 127; 1936, p. 51.

A three-course rotation[1] set up in 1933 confirmed the conclusion that the residual effects from composted straw and from straw ploughed in were small, though in this experiment they were always there. Over the two-year period the effect of the complete artificials was somewhat increased by the addition of straw:

Potatoes: tons per acre

Average 7 years 1934–40	*Complete artificials*	*Straw and artificials ploughed in**		*Straw compost*
		I	*II*	
Year of application .	8·50	8·94	8·21	7·10
First year after .	6·36	7·17	7·09	6·77

* In I all artificials are applied in spring; in II half in autumn, half in spring.

TABLE 9. *First-Year Effect and Residual Action of Organic and Inorganic Manures. Four-course Rotation. Rothamsted, average 7 years, 1934–40*

Manure tested	*Potatoes (tons per acre)*					
	Year of application	*1st year after application*	*2nd year after application*	*3rd year after application*	*4th year after application*	*Total of 5 years*
Dung,* 16 tons .	4·75	3·98	3·26	3·20	3·50	18·69
Straw compost .	3·51	3·36	3·02	2·78	2·45	15·12
Straw and artificials . .	4·99	3·66	3·58	3·45	2·92	18·60
Super., 8 cwt. .	5·57	3·96	4·16	3·88	4·03	21·60
Rock phosphate, 4½ cwt. . .	3·12	2·74	3·48	3·40	2·94	15·68

* Dung and straw compost both supply 50 cwt. organic matter per acre, i.e. sufficient straw is composted (rotted with addition of chemicals) to give 50 cwt. organic matter. All treatments are made up to a total of 1·8 cwt. nitrogen, 1·2 cwt. P_2O_5, 3·0 cwt. K_2O per acre. In the phosphate series the residues of phosphate only are tested; the nitrogen and potash are applied in five annual doses of 0·36 cwt. N and 0·6 cwt. K_2O, making the standard dressing of 1·8 cwt. N and 3·0 cwt. K_2O in the five-year period. See *Rothamsted Ann. Rept.*, 1932, p. 127, for details.

Poultry and Other Organic Manures

Poultry manure.—In peace-time considerable quantities of poultry manure are available and numerous experiments have been made to find its fertilizer value for different crops. It was used in the dried state, this being the most suitable form for transport, and its composition in the different seasons was not very variable: the average percentages in the samples used were: N 3·6, P_2O_5 3·3, K_2O 1·7. The experiments were

[1] *Rothamsted Ann. Repts.*, 1933, p. 118; 1936, p. 54.
In the three-course rotation the same amount of artificials is used in all four treatments, but in the four-course rotation deduction is made for the nutrients in the straw.

made both at Rothamsted and at outside centres during the period 1933–8: the average results are given in Table 10.

The increase given by the poultry manure is 57 per cent. of that given by sulphate of ammonia supplying the same amount of nitrogen.

TABLE 10. *Comparison of Poultry Manure and Sulphate of Ammonia. Tons Potatoes per acre*

	No. of experiments	*Yield No* N	*Increase for sulph. amm. (0·6 cwt.* N *per acre)*	*Increase for poultry manure (0·6 cwt.* N *per acre)*
Light soils .	16	7·74	1·62	1·20
Medium soils .	24	7·18	1·62	0·79
Heavy soils .	14	8·30	1·23	0·64
Mean .	54	7·63	1·52	0·87

Rape dust.—Four experiments have been made with rape dust, in three of which it came out inferior to sulphate of ammonia supplying equal amounts of nitrogen. The average of all the results was:[1]

Yield without N	*Increase for*		*Response to* N *in rape dust when that in sulph. amm.* = 100
	Sulph. amm.	*Rape dust*	
8·00	2·29	1·92	84

Other organic manures.—Single experiments only have been made, but in no case was the organic manure anything like so good as the sulphate of ammonia. The responses to nitrogen in the different substances compared with those for sulphate of ammonia as 100 were:[2]

Fish meal	*Meat meal*	*Malt culms*
43	5	61

[1] *Rothamsted Ann. Repts.*, 1934, p. 210; 1935, p. 212; 1938, pp. 194 and 195.
[2] *Rothamsted Ann. Repts.*, 1934, p. 210; 1935, p. 212.

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THE ROTHAMSTED EXPERIMENTS ON THE MANURING OF POTATOES

PART III. THE EFFECT OF FERTILIZERS ON THE HABIT OF GROWTH AND OTHER CHARACTERS OF POTATOES. GENERAL SUMMARY

SIR E. J. RUSSELL AND H. V. GARNER
(*Rothamsted Experimental Station, Harpenden, England*)

WITH PLATE 10

IN general, nitrogenous fertilizers in presence of sufficient potash and phosphate cause a marked increase in haulm and in depth of colour of the leaves, a considerable increase in the number of tubers and a lesser increase in their size. Potassic fertilizers lighten the colour of the leaves and keep growth continuing longer in dry seasons; they also increase the size of the tubers. Phosphatic fertilizers used with potash and nitrogen increase the number rather than the size of the tubers.

Plants receiving nitrogen and phosphate without potash may grow quite abnormally, especially in dry conditions. Their leaves become very dark green and some become rather coppery in appearance; the plants are small and growth is restricted. The life of the plant depends on its size: in the drought of 1921 the leaves and stems died earlier than when potash was given, though the yield was not much smaller: in 1940 the growth was so small that the soil moisture sufficed to keep the leaves turgid (Plate 10, figs. 1, 2). The crop given by nitrogen and phosphate without potash was actually less than that without nitrogen:

		P *No* N *or* K	*Increase for 0·6 cwt.* N
1940.	No dung .	7·18	−0·50
	Dung . .	8·45	+0·56

Farm-yard manure swamps all these special effects by supplying the complete plant nutrients. On the other hand, town refuse does not always do this, and in 1940 the plants receiving potash and town refuse but no nitrogenous fertilizer were light green and leggy, whilst those receiving nitrogen and town refuse but no potash were very dark green and in parts coppery and stunted; except when the plants were very small they wilted badly in the drought, and they died earlier than those receiving potash in addition. The combination of nitrogen and potash increased the growth of haulms and darkened the colour of the leaves.

Plants receiving no manure at Rothamsted show no special symptoms; they are smaller than the others, but normal in colour and survive as long as any others.

Effect of manuring on susceptibility to insect and fungus attack.— Extended observations were made both at Rothamsted and at Woburn in 1931 by L. M. J. Kramer[1] on the diseases caused by *Phytophthora* spp. (blight) and *Corticium vagum*. The diseases spread from certain centres

[1] Ph.D. Thesis, London Univ.

of infection, but neither these nor the direction of the spread seemed to have anything to do with the manurial treatment: the determining factor seemed to be the direction of the wind. This does not accord with the older idea that moderate manuring decreases the liability to disease whilst excess of any constituent, especially nitrogen or phosphate, increases it. In these particular observations the highest dressing of nitrogen was 3 cwt. sulphate of ammonia, which was clearly not excessive, but no subsequent observations have indicated any clear relation between manuring and incidence of disease.[1]

Observations on insect attack have been less systematic, but as far as they have gone they have not shown clear relations with fertilizer treatment.

Effect of manuring on the keeping quality of potatoes in the clamp.—This was tested in 1935.[2] The average loss of weight in the clamp between mid-October when the potatoes were lifted and February when the clamp was opened was 4 per cent., but with dung in the bouts and complete artificials it was about 6 per cent. Neither sulphate of ammonia, superphosphate, nor sulphate of potash affected the loss appreciably.

About 7 per cent. by weight of the potatoes went bad on storage; dung in the bouts increased this loss to nearly 9 per cent. Sulphate of ammonia had but little effect; superphosphate and potash did not decrease the loss but if anything increased it.

Effect of fertilizers on the size of tubers and the proportion of ware.—Throughout this paper the yield data refer to all the tubers gathered up: ware, i.e. the tubers saleable for food, seed, and chats. The proportions of ware have been ascertained in most of the experiments: they are not strictly comparable for all years as the size of the riddle over which the potatoes must pass is specified from time to time by the Potato Marketing Board. But they are comparable in any one year for the different plots, and so the results show how the proportion of ware is affected by the fertilizer treatment or the soil conditions.

The results up to and including 1936 have already been discussed in detail by one of us,[3] and we therefore give here only a summary including the more recent data.

On unmanured land the tubers tend to be small, and only 50 or 60 per cent. may be large enough to be sold as ware. Manuring markedly increases the size. There is a general relation between the yield and the size of the tubers, and in comparable experiments the percentage of ware increases with the yield.[4] But the effect of individual fertilizers is not quite the same on size as on yield. In most of the experiments sulphate of ammonia has increased the yield, but in only about half of them did it raise the percentage of ware, and then only by a small amount excepting where the initial percentage of ware was low. Superphosphate also increased the yield more often than it increased the ware. On the other

[1] At Susworth (Lindsay), 1939, the percentage of diseased tubers was:

0	1	2	3	cwt. sulphate of potash per acre
1·2	1·4	1·5	0·8	per cent. blighted tubers

[2] *Rothamsted Ann. Rept.*, 1935, p. 181.

[3] H. V. Garner, this Journal, 1937, **5**, 327–41.

[4] Loc. cit., p. 330, fig. 1.

hand, potash markedly increased the proportion of ware, and farm-yard manure still more. In all cases the effects are more marked when the initial percentage of ware is low, e.g. around 50 per cent.: where it is already above 90 per cent. fertilizers have no effect.

The effects are summarized in Fig. 3.

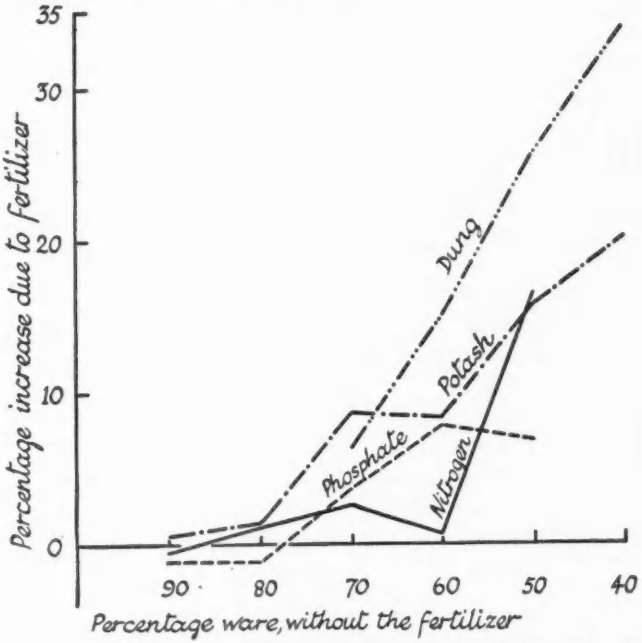

FIG. 3. Influence of manuring on the percentage of ware, i.e. the size of the tubers.

As in the case of yield the effect of farm-yard manure was somewhat greater when it was applied in the bouts than when spread over the whole field, and it was diminished by potassic fertilizer. The further addition of straw had no effect on the proportion of ware.[1]

Summary of Effects of Fertilizers on the Growth of Potatoes

Potatoes differ from most farm crops in responding freely to all three groups of fertilizers, and not chiefly to one or two, as often happens. The response to sulphate of ammonia is high: about 16 to 20 cwt. of potatoes containing about 320 to 400 lb. starch equivalent can be obtained per cwt. of sulphate of ammonia provided potash and phosphate are sufficiently supplied; this is more starch equivalent than can be obtained from any other crop for the same quantity of nitrogen. The response is not much affected by the soil type (except on the fens), the soil condition, the presence or absence of farm-yard manure, or the magnitude of the basal yield; it is the least variable of any of the fertilizer responses. But

[1] *Rothamsted Ann. Rept.*, 1937, p. 155.

it varies with the size of the dressing: the increase per unit of nitrogen is less for higher than for lower dressings; nevertheless, the rate of fall is slow and we have continued to obtain good increases for even the third or fourth hundredweight of sulphate of ammonia per acre. The full effectiveness of the sulphate of ammonia is obtained only when adequate phosphate and potash are present, and the relation with phosphate is more marked than that with potash, except on heavy soils. The nitrogenous fertilizer increases the yield partly by increasing the size of the tubers and partly by increasing their numbers, but except in poor soil conditions the chief effect appears to be the increase in number. There is no clear evidence that nitrogenous fertilizers affect the susceptibility of the leaves to disease.

The increases due to superphosphate may be even greater than those due to nitrogen, but they are not so widespread; 5 cwt. superphosphate has given responses of 3 tons or more per acre, though a more common increase is about 1 to 1½ tons per acre. The response differs from that to nitrogen in several ways: it usually falls off more steeply at the higher doses; it is more variable and more affected by soil and other conditions. Thus it is greater on heavy than on light soils; it varies on soils of different degrees of productiveness; on the heavy soil at Rothamsted it tends to be greater in years of low than of high yields, but this does not hold for the light soil at Woburn. The response is depressed by farm-yard manure. On the other hand, it resembles the response to nitrogen in that it is enhanced by potash.

Like nitrogen, phosphate increases both the size and the number of the tubers, probably the number more than the size. The combination of phosphate with excess of nitrogen and no potash may lead to harmful effects (p. 227); this does not often happen in practice, though G. A. Cowie has observed it in some of his experiments.

The response to potash differs from that to nitrogen and resembles that to phosphate in its rapid fall at higher doses, in its variability, and in its depression by dung. It differs from both nitrogen and phosphate responses in being more closely connected with the productiveness of the soil and the season, and is greater in poor conditions. It resembles both responses in being enhanced by the presence of the other two nutrients. Except on the fens there is no evidence that light soils are more responsive to potash than heavy ones.

The effect of potassic fertilizers on the size of the tubers is more pronounced than that of nitrogen or phosphate, and this may indeed be the chief cause of the increase in crop.

Potatoes differ sharply from mangolds and sugar-beet in that they are adversely affected by chloride; in our experiments 1 cwt. Cl per acre has reduced the crop by about 5 cwt. per acre. It is not clear whether sodium is harmful, though there is no evidence that it is beneficial. Magnesium in general is ineffective, but on a few soils, e.g. the Bunter sandstone, it has been beneficial. These results justify the growers' preference for sulphate of potash.

The fertilizers acted better when applied in the bouts than when broadcast.

No evidence could be obtained that manuring appreciably affected the liability to disease or the keeping quality.

The effect of soil type on yield is less than might have been expected in view of the marked preference shown by growers for light soils and loams. The determining factor is the ease of cultivation and especially of lifting, which is much greater on light than on heavy soils.

Farm-yard manure has a special value for potatoes, increasing both the yield and the percentage of ware, and the plots at Rothamsted and Woburn from which it is regularly omitted give only poor yields. Even on the fields which periodically receive dung its omission from the potato crop has lowered the yield by some 3 tons per acre. As already stated, farm-yard manure does not lower the effectiveness of sulphate of ammonia though it reduces that of phosphate and potash. The farm-yard manure is more effective when put into the bouts in spring than when spread over the whole field and ploughed under.

Rotting was no advantage: 15 tons of freshly made dung gave the same results as the 10 tons of rotted dung which it yielded after storing.

Straw composts were not as effective as dung.

The responses to the standard dressings of fertilizers are set out in Table 1. These are the increases over the means of all other treatments, and as shown in Part I, they are lower than if the comparison had been confined to plots fully supplied with the other nutrients, as would happen in good practice. But they may more nearly represent the conditions of ordinary practice.

The figures fall mainly on to simple distribution-curves. There are some apparent decreases, almost entirely in the range 0–10 cwt. per acre, but as the significant difference in an experiment is rarely less than 8 cwt. per acre,[1] a certain number of these figures simply mean that the fertilizer had no effect.

In absence of dung the responses to nitrogen are fairly widely distributed, about half of the increases are between 0 and 20 cwt., but some are as much as 40 cwt. of potatoes for 0·25 cwt. nitrogen, representing a recovery of some 65 per cent. or more in the crop. The results for phosphate are also widely distributed, but those for potash are peculiar in that they fall into two groups: most of the soils gave increases varying from 0 to 30 cwt., but a certain number form a special group giving increases of over 60 cwt. potatoes for 0·5 cwt. K_2O—representing an even higher recovery than for nitrogen.

In presence of dung the responses are all telescoped; the distribution of the increases is nothing like as wide; most are clustered round the groups 0 to 20 cwt. and few reach 40 cwt. The increases for potash are practically all in the group 0 to 30 cwt., and there is no sign of a second and higher group. This telescoping of the potash and phosphate responses can be attributed to the depressing action of farm-yard manure on their effectiveness, but the telescoping of the nitrogen effect cannot be so explained as there is no depression in this case. There were many more experiments without than with dung and this may account for the apparent discrepancy.

[1] H. V. Garner and J. W. Weil, this Journal, 1939, **7**, 369.

TABLE 1. *Numbers of Responses of the Specified Magnitudes to the Standard Dressings*

(0·25 cwt. N, 0·5 cwt. P_2O_5, 0·5 cwt. K_2O)

	Decrease		*Increase*						
Magnitude of response, cwt. per acre	*20 to 10*	*10 to 0*	*0 to 10*	*10 to 20*	*20 to 30*	*30 to 40*	*40 to 50*	*50 to 60*	*Over 60*
NO DUNG									
Nitrogen:									
Mineral soils, light and medium	1	6	16	26	11	10	5	1	1
,, ,, heavy	..	1	11	9	8	4	2	..	..
Fen soils, light	..	2	5	3	3	..	..	..	..
,, ,, heavy	..	..	..	..	3	4	..	1	..
Phosphate:									
Mineral soils, light and medium	1	8	6	6	6	1	..	..	1
,, ,, heavy	..	1	2	3	3	..	1	..	..
Fen soils, light	..	..	4	2	3	1	..	..	..
,, ,, heavy	..	..	..	2	1	1	3	1	1
Potash:									
Mineral soils, light and medium	1	4	13	8	5	1	1	1	3
,, ,, heavy	..	2	6	3	5	2	2	..	3
Fen soils, light	..	..	3	2	1	3	1	2	3
,, ,, heavy	..	2	6	..	..	..	..	..	..
WITH DUNG									
Nitrogen:									
Mineral soils, light and medium	..	4	12	5	2	3	2	..	..
,, ,, heavy	..	2	6	4	6	4	1	..	1
Fen soils, light	..	..	1	5	1	..	..	..	..
,, ,, heavy	..	..	..	..	3	..	..	..	..
Phosphate:									
Mineral soils, light and medium	..	5	9	..	2	..	..	..	1
,, ,, heavy	..	..	2	4	..	..	..	..	..
Fen soils, light	..	1	4	2	1	..	..	..	..
,, ,, heavy	..	..	..	2	..	..	..	..	..
Potash:									
Mineral soils, light and medium	..	2	8	10	4	2	1	..	..
,, ,, heavy	..	2	8	8	6	1	1	..	..
Fen soils, light	..	2	..	2	2	1	..	..	..
,, ,, heavy	..	..	1	1	..	..	..	..	..

Note: The responses are averages over all other treatments in the case of the recent factorial experiments.

The final results are collected in Table 2, where also are set out the averages obtained by E. M. Crowther and F. Yates for all the experiments made in Great Britain since 1900 to which they could obtain access.[1] As with other crops the Rothamsted average results are fairly close to the average for Great Britain.

[1] E. M. Crowther and F. Yates, this Journal, 1941, **9**, 77–97.

TABLE 2. *Summary of Fertilizer Effects on Potatoes*

	N (0·25 cwt. per acre)		P_2O_5 (0·5 cwt. per acre)		K_2O (0·5 cwt. per acre)	
	No dung	*Dung*	*No dung*	*Dung*	*No dung*	*Dung*
All centres . .	0·96	0·82	0·87	0·44	1·11	0·71
Rothamsted .	1·11	1·16	0·88	0·61	1·76	0·45
Great Britain .	1·07	0·86	0·84	0·55	1·23	0·55

Response to 10 tons farm-yard manure

	Dung alone	*Dung in presence of artificials*
All centres . . .	2·6	1·3
Rothamsted . . .	3·0	1·4
Great Britain . . .	2·8	1·4

The quantities of the dressings are arbitrary; if the effects are reduced to those produced by quantities proportional to the atomic weights of the three nutrients they become, for Rothamsted and its outside centres:

	N	P	K
Cwt. per acre . . .	0·14	0·31	0·39
Response, tons potatoes .	0·61	1·05	1·08

Effect of increasing dressings of a complete fertilizer.—The effect of increasing the dressings of mixed fertilizer of suitable composition was studied at several centres. At all except one the yield increased with the dressing, and on the fen and heavy loams the increase was substantial even up to the 18 cwt. dressing; no dung was given. On the Lincolnshire limestone soils the level of yield was low and the increments were somewhat less, though in absence of dung they still continued up to the 12 cwt. dressing. (Table 3.)

TABLE 3. *Increasing Levels of Complete Fertilizer*

Yield of potatoes (tons per acre)

Centre	*Soil*	*Yield: no artificials*	*Increase for fertilizer mixture cwt. per acre*						
			4	*6*	*8*	*12*	*16*	*18*	
Midland College (5 expts. 1934–9)	Good light loam	9·64	0·56	..	0·35	0·31	..	..	Dung
Lincolnshire . (5 expts. 1935–7)	Limestone	5·67	0·97	..	1·92	2·35	..	..	One with, four without dung
Three good potato farms (1939) .	2 fens; 1 heavy loam	9·83	..	1·91	..	3·25	..	4·03	No dung

Manurial Practice

The recommendations for the manuring of potatoes have varied somewhat since the time when Augustus Voelcker made his first experiments

seventy years ago.[1] He then used a mixture of approximate composition $N:P_2O_5:K_2O = 1:1:1$, but gives no reasons for his choice. Lawes and Gilbert used more potash than phosphate. Then came a period when the proportion of phosphate was increased. A. D. Hall in 1909 suggested $N:P_2O_5:K_2O = 1:2{\cdot}5:2{\cdot}5$. Many of the 'compounds' sold to farmers, however, contained less potash. The more recent work at Rothamsted indicated that more nitrogen and more potash should be used, and the proportions suggested before the war were 1:1:1–2.

	Voelcker 1870	*Lawes and Gilbert 1883*	*Good practice 1900*		*A. D. Hall 1909*	*Rothamsted*	
						Usual	*Heavy fen*
			(*a*)	(*b*)	(*c*)		
N	1	1	1	1	1	1	1
P_2O_5	1	0·7	1	1–1·5	2·5	1	2–3
K_2O	1	1·6	0·8	1·5	2·5	1–2	1

(*a*) A well-known manure dealer. (*b*) Primrose McConnell, *Agricultural Notebook*. (*c*) *Fertilizers and Manures*, 1909.

The Rothamsted combination is based on the experiments described in this paper, but it is intended only as a framework to be modified according to conditions. Farm-yard manure should be the basis of the manuring; 15 tons per acre may give 2 or 3 extra tons of potatoes. In view of the good response to sulphate of ammonia and the fact that it goes on to the third and sometimes the fourth hundredweight per acre and is not curtailed by farm-yard manure, we suggest that 3 cwt. should be the normal dressing, to be increased to 4 cwt. if the other conditions allow of yields of the order of 9 or 10 tons per acre. The dressing of superphosphate must depend partly on the soil; heavy soils being more responsive can have 4 cwt. per acre, and heavy fen soils 5 cwt. or even more. The yield does not continue to rise with the higher dressings quite as well as with sulphate of ammonia, but the increments may still be profitable. Light soils may be less responsive and 3 cwt. may suffice, though higher dressings should be tested. About potash it is more difficult to generalize: 2 cwt. sulphate of potash could be taken as a normal level, to be increased if supplies of dung are short, or decreased if they are larger or the soil is in a condition of high productiveness. As between the sulphate and the muriate of potash there is little to choose, but the lower-grade salts may involve loss of crop, as their chlorides reduce the yield and there is no evidence that either sodium or magnesium normally increases it.

It is recognized that in war-time the quantities of potash involved in this recommendation are not available. If all potato-growers were equally good the most economical use of restricted potash supply would be on the soils in poor condition, as it is these which usually give the greatest response. But there are other factors besides soil condition, and the rationing of potash involves a variety of considerations.

[1] A. Voelcker, *J. Roy. Agric. Soc. Eng.*, 1870, **6**, 392.

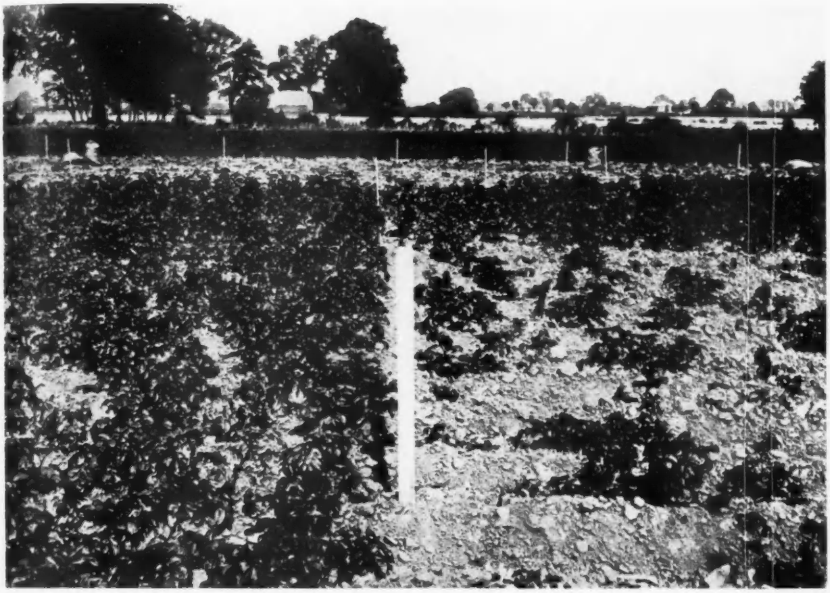

FIG. 1. Effect of absence of potash in year of exceptional drought. (Jan.–Sept. 10·94 inches.) No dung given. Left: N, P, K. Right: N, P.

FIG. 2. Foliage-effects in year of moderate rainfall. (Jan.–Sept. 17·11 inches.) No dung given. Left: NP very dark green. Right: PK very light green.

Manuring of ploughed-out grass-land.—Potatoes can very suitably be grown as a first crop on newly ploughed grass-land. At Rothamsted the need for potash is as great, and for nitrogen almost as great, as on the arable land, indicating that the grass residues supply only small amounts of nitrogen and potash to the crop. The response to phosphates is somewhat less than on the arable land, but this should not be regarded as generally true.

TABLE 4. *Fertilizer Response on Ploughed-out Grass and on Old Arable Land. Rothamsted, 1939–41*

The responses are calculated to the standard dressings N 0·25 cwt., P_2O_5 0·5 cwt., K_2O 0·5 cwt.

Fertilizer applied	*1939*		*1940*		*1941*	
	Basal	*Increase*	*Basal*	*Increase*	*Basal*	*Increase*
Ploughed-out grass						
0·25 cwt. N	..	..	8·58	+0·52	8·51	+0·17
0·5 cwt. P_2O_5	6·89	+0·58	8·83	+0·34	8·43	+0·32
0·5 cwt. K_2O	6·85	+0·63	7·84	+1·90	7·75	+1·67
Old arable						
0·25 cwt. N	..	..	7·32	+0·24	4·28	+0·88
0·5 cwt. P_2O_5	6·29	+1·47	..	..	4·43	+0·59
0·5 cwt. K_2O	6·40	+1·05	6·76	+1·10	3·88	+1·69

No dung was given in any of these experiments.

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LENGTH OF LIFE AND INTERVAL BETWEEN GENERATIONS IN THE LARGE WHITE BREED OF PIGS

H. P. DONALD

(*Institute of Animal Genetics, University of Edinburgh*)

Introduction.—Profit in the pig industry is largely determined by the number and size of the litters produced by sows in their lifetimes. Genetically, improvement of such a character depends on the recognition of superior sows and the use of their sons and daughters for breeding. Such recognition becomes more certain the longer the life-history of sows and the more extensive the records of performance of daughters [1, 2].

The object of the investigation now reported was to determine the amount of information about sow performance which was usually available to breeders in the selection of their young breeding stock, and to inquire whether that amount is utilized. Since improvement is, for the most part, bound up with pedigree breeding, samples relating only to pure-bred Large Whites have been taken as representing the most numerous pure-bred pigs in Great Britain at present.

Length of breeding-life has been estimated in three ways. No direct calculation is possible, since dates of death are not available. The first estimate was therefore made from records of notified litters which give an estimate in terms of litters produced. The second was taken from the average age of sows (at a fixed time) in thirty-nine herds of varying size at a specified date, and the third was taken from the average interval between generations. This last method permitted an estimate to be made for boars as well as sows. A combination of the second and third methods was used to make inferences about the ages of sows when those daughters which are subsequently retained for breeding are born.

Length of breeding-life of sows.—Through the courtesy of the National Pig Breeders' Association access to the performance records of Large White sows has been possible. These give a fairly complete breeding-history of each sow.

The current files contain cards for all sows which, regardless of age, have farrowed one or more litters during the last 3–4 years. From these files 1,171 cards were chosen at random and the numbers of litters recorded on them noted. No records, of course, existed for any young sows still to wean their first litter.

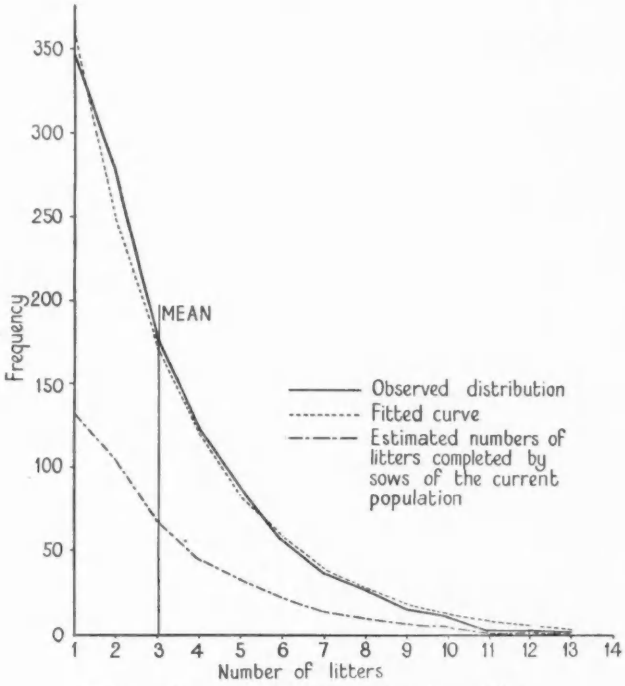
Graph 1 shows the frequency distribution of number of litters recorded.

Can such accumulated data be used as a basis for estimating the shape of a cross-section of the population at any moment?

Under the conditions of sampling, the data include two types of sow history, (*a*) finished, and (*b*) unfinished. The former comprises the complete records of all sows concluding their productive lives during the stated period and the latter all sows which were producing litters

towards its end. Of the latter, a proportion would be discarded, but they cannot be distinguished from those which would be retained. The sample, therefore, represents the breeding-history of an existing sow population plus an accumulation of completed histories from previous populations.

It has several defects of unknown magnitude which, fortunately,



GRAPH 1. Frequency distribution of numbers of litters.

tend to cancel each other. There are doubtless many young sows whose first litters are not notified. The second may appear as the first, or the sow may not be represented at all. Again, new breeders starting a herd may notify their sows' first litters, but fail to continue the process. It is thus the early litters which are likely to be most affected, but the conclusions to be drawn from the data will not err much on that account. The theoretical justification for accepting them requires more extended treatment.

The frequency data shown in Graph 1 approximate closely to an exponential curve of the form $Y = 360(0{\cdot}693)^{x-1}$. Fitted values, also shown in Graph 1, lie close to the observed values except in litter class 2 and at the tail of the distribution which involves the very old sows. The deviations, when tested by the χ^2 method, lie between the

0·1 and 0·05 levels of probability, and are thus not significant, but the theoretically expected sows of great age will not be found in practice.

If the exponential curve is accepted as a description of the data, it follows that each litter class is about 0·7 of the size of the preceding class. In the sequel the rate of decline in class size will be called $(1-p) = 0{\cdot}3$, and it may be shown that $(1-p)$ obtained from the data of Graph 1 is the same as $(1-p)$ in the living population at any time.

Suppose that there are Y living sows in litter class 1. Then the number in the succeeding classes will be pY, p^2Y, and so on. After a period of about 6 months breeders will have decided for each sow whether she should be discarded after her current litter or retained for further breeding. Young sows will be introduced to maintain herd size, but the sows discarded will still be represented by a card showing the number of litters they had produced. Sows disposed of after their first litter (or lost by disease and accident) will have a card with one entry, and during the second 6 months there will accumulate $Y+(1-p)Y$ cards with one entry. During the third 6 months, $Y+2(1-p)Y$ such cards will accumulate, and similarly for the other litter classes. Thus:

Litters completed by living sows		
Number	*Frequency*	*No. of cards after* n *periods of 6 months*
1	Y	$Y+n(1-p)Y = Y(1+n(1-p))$
2	pY	$pY+n(p-p^2)Y = pY(1+n(1-p))$
3	p^2Y	$p^2Y+n(p^2-p^3)Y = p^2Y(1+n(1-p))$, &c.

The number of cards accumulated for each litter class is therefore the number of living sows in each class multiplied by a constant number. The relationship of each class to the next is unchanged by this process. It may be concluded, therefore, that a distribution of the type found can be obtained from an existing population with the same characteristics. It does not follow that it was so obtained, but if it was not, an unlikely combination of changing rates of discard would be required to explain the final result.

Past and present sows are now assumed to be of the same distribution among litter classes. The first consequence of this is that the sample mean gives not only the mean number of litters produced by sows in their lifetime, but also the mean number of litters produced by sows still living, and with at least one litter to their credit. In other words, the average length of life in terms of litters is the same as the average age (of sows with at least one litter) in the same terms. The inclusion of young sows which have not weaned their first litter would, of course, reduce the average age. On these figures, the replacement rate among brood sows reaches the high value of approximately 30 per cent. every 6 months (cf. [3] on dairy cattle).

The second consequence is that the expectation of life (again in terms of litters) of a sow, no matter whether she is just beginning her productive life or is some way through it, is about three litters. Defining expectation of life as the average *further* length of life attained by sows of the same age, then it is clear that a gilt will, on the average, live to

produce three litters. Owing to the uniform rate of decline in the litter classes, it does not matter where the origin is made—the mean will always be three litters from the origin. It is a property of the exponential distribution that the mean of the frequencies is the reciprocal of the rate of decline in class frequencies. In the present example the mean number of litters produced over the whole sample might have been calculated as follows:

Total number of sows in the living population $= Y(1+p+p^2...)$
Total number of litters produced $= Y(1+2p+3p^2...)$
Mean number of litters per sow

$$= \frac{Y(1+2p+3p^2+...)}{Y(1+p+p^2+...)} = \frac{1}{(1-p)^2}\,\frac{1-p}{1} = \frac{1}{1-p}.$$

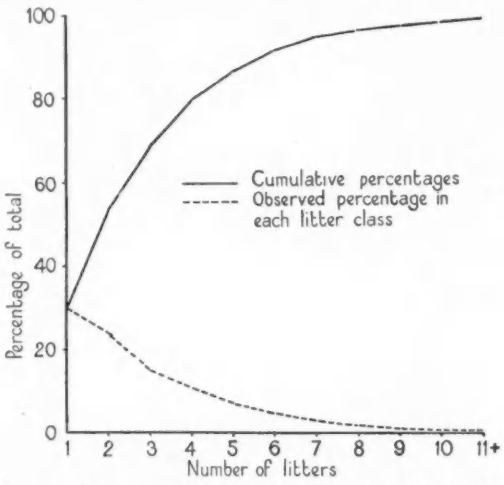
Substituting 0·307 for $(1-p)$, the mean will be 3·26, which is reasonably close to the actual value 3·01, considering the deficiency of aged sows. Some allowance must be made for this shortage, especially as the origin approaches the aged classes. The expectation of further life will, in fact, be somewhat less than three litters for the older sows. It follows that, in order to raise the average performance of sows to four litters, the rate of discard will have to be lowered from the observed 30 per cent. to something under 25 per cent., say 22 per cent., provided it remains constant in the new conditions.

The number of living sows in any litter class of the whole sample (Graph 1) which will pass on to the next litter class can now be estimated. During the period of 40 months in which the present data were accumulated a sow could produce six or seven litters. Between every two litters, that is once every 6 months, sows will have to survive the possibility of being eliminated. Supposing $(1-p)$ of each class of living sows fail to survive each time, about $6{\cdot}5(1-p)$ sows will be the total failures during the period in each litter class. The total number in each class of the sample will be this group plus the sows which have just achieved any particular number of litters and will go on to the next, that is p. Thus for litter class 1, $[6{\cdot}5(1-p)+p]Y = 349$, where Y is the number of living sows in the sample. Substituting 0·7 for p, Y becomes 349/2·65, or 178. Litter class 2 will include 278/2·65 or 105 living sows, and so on. Only pY sows, however, will proceed to the next class. It is these which are shown in the lowest curve of Graph 1. The values adopted are admittedly based on the rather optimistic assumption that sows farrow every 6 months. The half-yearly groups of discarded sows are probably somewhat fewer than 6·5. If 6·0 is used instead, values about 6 per cent. higher would be obtained.

From the point of view of breed-improvement, it is useful to visualize the productivity of sows in terms of the proportion which fall within any desired limits. This has been done for the observed data of Graph 1 by continuous summation and conversion to a percentage basis. The result is shown in Graph 2. The curve is again an exponential with the same rate of change in class-frequency but inverted. It shows that 54 per cent. of sows do not rear more than two litters, and 69 per cent.

not more than three litters. There is obviously much scope for improvement.

Interval between generations.—As a rule young sows are about 6–7 months old when the decision to retain them for breeding or dispose of them for slaughter is finally taken. At this time their dams may have farrowed again, but they will not have weaned the next litter. The amount of information about the performance of the dams which could

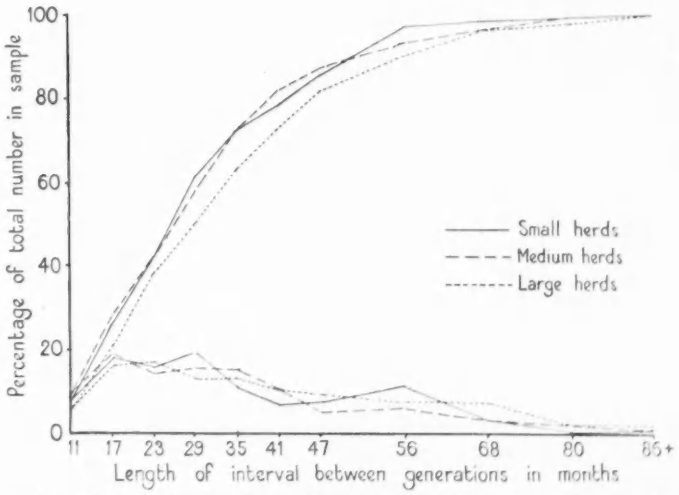


GRAPH 2. Percentage distributions of sows in each litter class.

be used in the selection of gilts is thus more or less confined to the litters in which the gilts are born together with any previous to these. The age of a sow at the time a daughter is farrowed thus indicates what is known of her when the daughter is selected. This age was easily obtained from the difference in the dates of birth of dam and daughter which are published in the herd-books for all registered sows. Some thirty-nine herds have been studied. These herds were chosen at random except that it was arranged that three size-groups (Table 1) should be adequately represented. In each herd all sows which farrowed during the period January 1 to June 30, 1939, were noted together with date of birth, and number of litters produced up to this time. The dates of birth of their dams were also obtained, and then the age of the dams when the present sows were farrowed.

The resulting differences between the dates of birth, or as they are called, the intervals between generations, have been classified and the frequency-distribution plotted on a percentage basis for each size-group of herds. Graph 3 shows these distributions and Table 1 the parameters (for statistical methods, see Aitken [4]). They are all very skew and flat. Both sets of coefficients are quite significant when compared with their errors ($\sqrt{6/N}$ for $\sqrt{\beta_1}$, and $\sqrt{24/N}$ for $\sqrt{\beta_2}$).

In the large herds, however, the mean was relatively high, owing to a greater proportion of old sows, and associated with greater variance and flatness. Since an analysis of variance showed that the observed mean intervals could have arisen from the same population by chance in less than 1 per cent. of samples, the effect of herd-size must be judged significant. The cumulative percentage curves (Graph 3) bring out the difference between the larger and lesser herds. From them may be



GRAPH 3. Distribution of length of interval between generations of sows; above, cumulative percentages; below, class percentages.

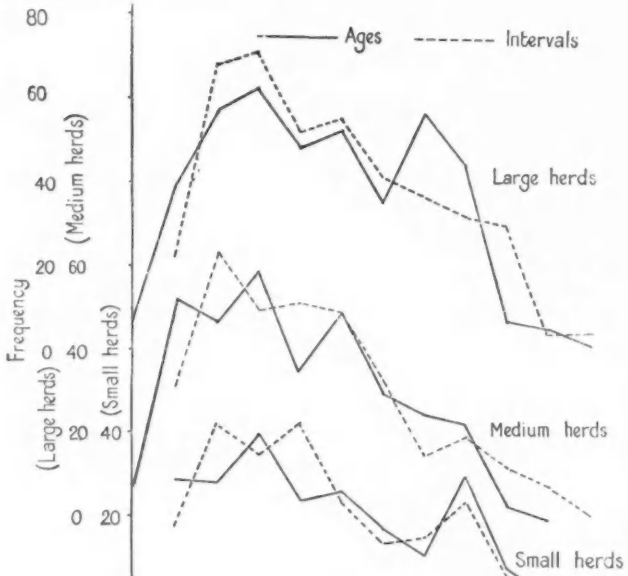
read off directly the percentage of all the dams which were less than any given age when their daughters were born. For instance, 60 per cent. of the sows in the medium and small herds were farrowed by dams not more than 26–32 months of age, whereas 50 per cent. were farrowed by such dams in the large herds.

TABLE 1. *Age of Sows and Mean Interval between Generations (in months) in 39 Herds*

Herd size	*No. of herds*	*No. of sows*	*Mean age*	*Interval between generations*			
				Mean	σ	$\sqrt{\beta_1}$	β_2
Large (> 35 sows)	9	439	33·3	35·1	4·5	1·1	4·5
Medium (21–35 sows)	13	350	28·2	31·4	4·1	1·1	4·0
Small (< 21 sows)	17	236	32·7	31·4	3·7	0·8	3·2

Relation between age of dam and interval between generations.—Since Graph 1 shows an age-distribution of sows in terms of litters it cannot be used to compare ages and intervals both in months. The comparison however, is desirable in order to show whether daughters tend to be

chosen from any particular sow age-class, or are chosen without reference to the length of their dams' breeding history. If the former alternative is true, the distributions of ages and intervals will differ, since certain age-classes will have relatively numerous or relatively few daughters; and if the latter, they will be similar, since the number of daughters will be proportional to the number of sows in each age-class.



GRAPH 4. Distributions of ages of sows and of intervals between generation of sows.

Data from the same thirty-nine herds have been used. Since there may conceivably have been some correlation between the age of a sow and the age of her dam when that sow was born—a tendency perhaps for the old sows to have been farrowed by old dams—these were plotted against each other. The diagrams, however, showed no indication whatever of such a correlation.

Graph 4 shows the distributions obtained, this time in absolute frequencies. For each herd-size the agreement in the shapes of the curves must be considered good. The means (Table 1) are also in close agreement, and support the conclusions arrived at from study of the data of Graph 1.

On this evidence it seems very likely that the number of sows in each age-class determines the number of daughters chosen for breeding. Implicit in this is the conclusion that, on the whole, daughters from

old sows are not favoured, or more generally, that the length of a sow's breeding history is not given much weight in the selection of gilts. Breeders who intend to select for consistent performance may actually be achieving less than they hope (cf. [5] for dairy cattle).

Intervals between generations of boars.—Methods other than those used for sows have had to be adopted for boars, partly because there are too few boars in the herds studied, and partly because practical reasons often require a change of boar before his usefulness is over.

Recourse has been made to the herd-books of the Large White breed for random samples of boars, and for these the dates of birth of the boars themselves, their sires and paternal grandsires, have been obtained (month and year only). Two samples have been taken, one from the 1939 herd-book (vol. 55) and one from the 1926 herd-book (vol. 42), in each case by taking entries at fixed points on each page. For both samples there are therefore two sets of differences in dates of birth, the first between boar and sire and the other between sire and paternal grandsire.

Frequency-distributions and cumulative percentage curves showed a general similarity to the corresponding data for sows in Graph 3. The parameters for the distributions show that as before they are both skew and flat (Table 2).

TABLE 2. *Interval between Generations of Boars*

		No. of pairs	*Mean (months)*	σ	$\sqrt{\beta_1}$	β_2
Boar and sire	Vol. 42	200	27·2	3·1	1·4	5·2
Sire and paternal grandsire	Vol. 42	200	28·2	3·0	1·3	5·0
Boar and sire	Vol. 55	324	26·5	3·1	1·6	5·8
Sire and paternal grandsire	Vol. 55	324	28·5	3·9	1·6	5·4

No important differences between the two samples are evident. If the means apply to the populations from which the samples are drawn, then the average age of sires when their sons are born is about 27 to 28 months, or about 18 months of breeding-life. This is close to the value of 2·44 years found by Lush and Anderson [6] for recent generations of the Poland-China breed. It is not forgotten that some sires leave many registered sons and probably the great majority leave none. The same thing will be true to a lesser extent for sows, but this would not alter the fact that a great many boars retained for breeding are sired by animals with a comparatively short breeding-history.

Interval between generations of notable families and tribes.—A record of the most successful modern families through the male line and another through the female line has been prepared as far back as the foundation animals of the Large White Herd-book [7]. This provided an opportunity for determining whether or not the favoured breeding-lines differed from the general population in respect of interval between generations, particularly since experience has shown that the great majority of pigs in pedigree herds can be traced to a family within a few generations.

The tables were divided into two parts: (1) animals born between 1933 and 1919, and (2) animals preceding these as far back as the foundation animals (1884–1919). For the first part, dates of birth for each pig were available and from these frequency-distributions comparable with those above were constructed. The second part will be discussed later.

The relevant parameters for recent boars and sows (1) are as follows:

TABLE 3

		Interval between generations			
	Number	*Mean (months)*	σ	$\sqrt{\beta_1}$	β_2
Boars . . .	154	30·9	3·7	1·3	4·7
Sows . . .	214	30·4	3·4	1·2	5·8

As before, the distributions are skew and flat, and resemble those of less select groups of animals. Reference to Table 2 will show that the mean interval for boars is rather longer than that previously obtained, but the difference is of the order of only 2 to 4 months. On the contrary, the mean interval for the sows is somewhat less, though not significantly less than in small herds. The degrees of skewness and flatness are substantial and quite significant, but not so marked for the boars as in the random samples (Table 2).

In respect of skewness the coefficient in each sample of intervals between boar generations is greater than in any sample for sows. On the null hypothesis that the degree of skewness is actually the same for boars and sows, the likelihood that each of the 5 boar samples would exceed all 4 sow samples is $\frac{5!\,4!}{9!}$, or 1/126. A real difference between boars and sows is indicated.

Individual dates of birth were not available for animals registered in the early volumes of the herd-books [2], so that another method of estimating the length of interval was adopted. Each 'tribe' consists of a number of families tracing back to the same foundation boar or sow. Apart from the dates of birth of these foundation animals (kindly supplied by the National Pig Breeders' Association), the earliest available dates were about 1919–20, the intervals between being occupied usually by 13 to 20 generations. Whereas there was only one foundation animal for each tribe, the number of families arising during the interval was often more than one. The average date of birth of all pigs an equal number of generations away from the foundation animal was therefore calculated and used in measuring the length of interval, which was then divided by the number of generations occurring within it. In some of the tribes the foundation animal itself or an immediate descendant united distinct groups of families and in such cases two or more estimates of average interval were made.

It may be seen from Tables 2, 3, and 4 that the interval between boar generations gradually rises from about 27·5 months for a random sample, through 30·9 months for recent selected animals (in itself a

significant increase), to 32 months for distant but more rigorously selected sires. Famous sires are often followed by their most notable sons after a long period of service in large herds. One tribe of boars, for instance, averaged 40·2 and another 39·4 months. In both, large gaps in the herd-book numbers suggested that certain sires were responsible for the high values.

TABLE 4

	No. of tribes or sub-tribes	*No. of generations*	*Average length of interval between generations (months)*
Boars . . .	7	87	32·0
Sows . . .	28	341	32·5

The same cannot be said of the sows, although marked differences among the tribes, ranging from 26 to 44 months, were found. The most select group (Table 4) showed an even lower mean interval than did the large herds (Table 1). Success of the kind achieved by these families has therefore not depended to any great extent on proof of their ability to sustain long lives of high performance.

Discussion

Raising the average length of breeding-life of sows would combine economic with genetic advantages. Fewer young sows would be required for replacements, so that the standards required of them and of their dams could be raised. This point is worth attention, since there are at present so many sows which do not live long enough to provide sufficient information about their powers that progress in the breeding of improved sow types is seriously hindered. It might seem to be a simple matter to select gilts only from those sows which have given a satisfactory lifetime performance, but the evidence suggests that in general this is not done. Several reasons may be suggested:

(1) Breeding sows have too short a life to provide enough suitable young sows for replacements and sale as breeding stock, unless daughters from their early litters are kept.
(2) Buyers do not demand breeding stock from old sows.
(3) Selection for early maturing pigs of the right bone-meat-fat composition at bacon-weight may be incompatible with the production of a non-fattening, small type, heavy milking mother of good stamina [8].
(4) Emphasis in the selection of sows is placed mainly on other characters such as conformation or fecundity.
(5) It pays to discard sows while still comparatively young because of an undesirable tendency for old sows to become heavy and clumsy.
(6) It may not be generally realized that no reliable guide to breeding-value in respect of mothering qualities can be obtained from the records of one or two litters.

An average of three litters per sow cannot be regarded as satisfactory

for the whole pig industry, and must contribute largely to the short-duration characteristic of many of the smaller herds. The poor performance of many sows has even given rise to the opinion, noted in a Ministry of Agriculture Bulletin [9], that sows should be discarded after their fourth litter. The remedy would seem to lie in greater attention on the part of pedigree breeders to the production of reliable sows.

Summary

1. In a random sample of records of the breeding history of 1,171 sows the numbers of litters produced were distributed along an exponential curve of the form $Y = 360(0{\cdot}693)^{x-1}$ (Graph 1).

2. It is shown that with such a distribution the mean number of litters produced by sows in their lifetime, the mean number of litters already produced by living sows with at least one to their credit, and the expectation of life of at least the younger classes of sows (all in terms of litters) is, in each case, approximately three litters. Brood sows are replaced at the rapid rate of about 30 per cent. every 6 months.

3. According to this sample 69 per cent. of sows produce three or fewer litters in their lifetime (Graph 2).

4. The mean interval between generations of sows was about 31 months in 30 small and medium-sized pedigree herds, and 35 months in 9 large herds, the difference being significant. Owing to the skew distribution of the intervals, about 60 per cent. of the dams were not more than 26 to 32 months (3 to 4 litters) old when their selected daughters are born (Graph 3, Table 1).

5. The close similarity in the shape of the distribution of the age of 1,025 sows at a fixed time and of the age of the dams of these sows when they were born suggests that the numbers of sows in any age-class determines the number of daughters selected from that class, and that the length of breeding-history of dams is not given much weight in the selection of daughters (Graph 4).

6. The interval between generations of boars shows the same general skew and flat distribution as that of sows, but the mean tends to be lower, ranging from 27·2 to 28·5 months (Table 2).

7. In a highly selected group of boars and sows the mean interval between generations of recent animals was higher than in the random samples for boars and lower than in the random samples for sows—30·9 and 30·4 months respectively. More distant generations back to the foundation animals of the early herd-books yielded higher values, namely, 32·0 and 32·5 months. There appears to be a tendency with boars (but not sows) for the interval between generations to increase slowly when passing from a random sample to the most select groups (Tables 3 and 4).

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RESEARCH IN POULTRY NUTRITION IN WAR-TIME

H. TEMPERTON AND F. J. DUDLEY

(*National Institute of Poultry Husbandry, Harper Adams Agricultural College*)

Introduction.—The research policy of the National Institute of Poultry Husbandry was reviewed upon the outbreak of war, and it was decided to suspend the existing programme with its problems of peace-time interest, in order to concentrate upon the new difficulties which would arise, particularly in the nutritional field.

The experiments which have been carried out since then have been concerned with the difficulties existing at the particular time of their planning. In some cases, so rapid have been the changes in the food situation, brought about by political and military operations, that the purpose of the investigation has lost its immediate practical bearing before the results have become fully available, in particular when certain imported foodstuffs and grains became no longer available for poultry-feeding.

When hostilities began, the future position of the animal feeding-stuffs trade was very speculative. It was presumed that temporary shortages of various foodstuffs might be experienced through shortage of shipping-space and difficulties in local distribution.

A series of experiments was undertaken to examine the practicability of using, as substitutes for ingredients which might be difficult to obtain, some of the foodstuffs which, though apparently of suitable chemical composition, had, for various reasons, not found a place in peace-time rations for poultry. In the choice of these substitute foods regard was paid to their probable availability, either because they came from Empire or other friendly countries, or because they were by-products of essential industries.

As substitutes for the carbohydrate portion of poultry rations, in particular milling offals and maize meal, the value of tapioca (manioc) meal, extracted palm-kernel meal, and coconut meal has been investigated, whilst as alternative sources of protein, decorticated ground-nut meal, brewer's yeast, and 'fodder' yeast have provided material for further tests.

The winter of 1939 produced a shortage of carbohydrate foods, particularly maize meal and wheat offals, whilst protein foods, with the exception of soya-bean meal, were still in fair supply. The difficulty seemed to be due to irregular distribution rather than to a national shortage, but it directed attention to the need for obtaining information on the value for poultry of home-produced feeding-stuffs, for which the demands of human consumption are not likely to compete with those of poultry.

The urge of the Minister of Agriculture for an increased acreage of potatoes suggested that large quantities of chat potatoes would be available, provided that the poultry-keeper could compete successfully with the pig-keeper.

Experiments were started, therefore, to ascertain what levels of potatoes and other roots could be used for different classes of poultry as partial substitutes for concentrated carbohydrate foods.

Synchronizing with this development, supplies of dried potato meal became available. With the elimination of most of the water in the potato when converted into dried meal, the problem was to determine whether it could be used for different classes of poultry at a higher level, on a dry-matter basis, than cooked potatoes, and thereby conserve a greater weight of cereal food.

The public interest, about this time, was being aroused to the necessity for making the best use of edible household waste, and the collection and drying of this material was already being undertaken in some of the larger towns. Samples of town food waste, though varying considerably, as would be expected, had an average composition very similar to that of a normal ration for laying birds. In our experiments with it, therefore, the town waste was used as a substitute for the total ration.

In the spring of 1940 details of the impending scheme for the rationing of feeding-stuffs were announced, indicating that from the autumn of 1940 the supplies of purchased foods available for poultry would probably not suffice for more than about one-third of the normal poultry stock of the country. This prospect pointed clearly to a very drastic reduction of poultry stocks, to be mitigated only by the use of substitute home-grown foods and the securing of greater efficiency in the use of purchased foods.

Before the war a series of experiments was in progress at the Institute on the controlled feeding of chickens during the rearing stage. These were designed to test the validity of the criticism raised from time to time that the popular system of feeding chickens by allowing them unrestricted access to mash, supplemented by grain feeds, was uneconomic, since it afforded no stimulus to grazing, and was a probable predisposing cause of intestinal parasitism through the overloading and weakening of the digestive system.

This work now assumed a new significance, since with a fixed total supply of food the head of stock that could be maintained must obviously be determined by the average consumption per bird. Consequently the experiments on restricted feeding were extended to embrace not only the rearing of chickens but also the egg-production of pullets and the rearing of goslings.

The announcement in April 1941 of a further reduction of food for poultry to one-sixth of the normal supply has resulted in a search for a more drastic means of food-restriction, coupled with a fuller use of home-grown foods. In this connexion the value of young grass, fresh and ensiled, as replacements for normal foods is now under investigation.

The rapid changes in the problems which have arisen since September 1939, and the necessity for getting quick guidance on the probable trend of the results, have made it necessary in most cases to curtail the duration of the egg-production studies well below the full year that would normally be required. For this reason more stress will be placed on the qualitative than on the quantitative aspects of the results in these cases.

At the same time the curtailment of the period of test has in certain cases given greater scope for replications, and the redistribution of groups for further tests has provided a means of ascertaining any residual effects of foods consumed in a previous test. In this connexion it is noteworthy that frequent changes in rations necessitated by uncertain supplies, and in some instances considerable changes in feeding from one test to the next with the same birds, have not resulted in the dire consequences that conventional opinion would have predicted.

In view of the volume of work covered by this review and the limited space available, it is impracticable to give full details of the results obtained and of the methods of their statistical evaluation. Some of the tests have been little more than qualitative demonstrations, without replication, of the practicability of using certain foodstuffs, but in most instances there have been replications, rendering the experiments comparable with crop experiments in randomized blocks. The difficulties of statistical analysis arising from the variation in numbers of birds in the sub-groups, and in certain cases a missing sub-group, have been overcome by fitting constants, by the method of proportionate numbers in the sub-groups or by the method of weighted squares of means, as seemed appropriate in each particular experiment. Reference is made to experiments already reported elsewhere, and the more important results of unpublished work are included in the text.

Substitutes for Carbohydrate Foods

Extracted palm-kernel meal.—Palm-kernel meal (extracted) is not unlike bran in its content of protein and fibre, but is much less bulky. It must have been fairly widely used during the later years of the Great War, but little record of experience in the use of it can be found in the literature. At the Institute a test of its value at two levels of replacement was made with White Leghorn and Rhode Island Red × White Leghorn pullets, housed in individual cages in a laying-battery with no artificial light, and fed solely on dry mash [1]. The control ration contained 20 per cent. of wheat middlings and in the experimental rations one-half and the whole, respectively, of the middlings were replaced by palm-kernel meal. As an addendum, a test was made of a further experimental ration in which one-half of the middlings was replaced by palm-kernel meal and the whole of the protein concentrates (fish meal and dried skim milk, together forming 8½ per cent. of the ration) by 10 per cent. extracted decorticated ground-nut meal.

The ration containing palm-kernel meal proved very satisfactory. With cows and sheep there is often a difficulty at the start in getting the stock to eat this meal, but no such difficulty was experienced with the birds in this experiment. Over a period of 36 weeks the health of the stock was unaffected, production was maintained at as high a level as on the control ration, at over 120 eggs per bird, and as in the case of the control ration, the body-weight increased by some 4–5 oz. The use of decorticated ground-nut meal did not give so high a level of production, but whether this was a purely nutritive effect is doubtful.

Tapioca meal.—Tapioca (manioc) meal has a very high starch-content,

nearly 80 per cent., and hence would appear to be a very suitable alternative to foods like maize meal, weatings, and ground oats. Much of it is in a fine floury condition, and from a limited practical experience of the use of this kind of material the view has been developed that not more than about 10 per cent. of it by weight should be used in mashes, because of the risk of making the ration unpalatable and the danger of causing constipation. To test the validity of these opinions a trial was undertaken with Rhode Island Red hens in a semi-intensive house [2]. In the experimental ration, which, like the control ration, was fed dry, an extreme level of 40 per cent. of tapioca meal was used to replace parts of the bran, weatings, and maize meal of the control ration, the protein-content being maintained by a substantial increase in fish meal. The birds were given 1 oz. of grain per head per day.

In a period of 24 weeks the average production of the hens on the tapioca ration was 62·4 eggs per bird compared with 69·9 on the control ration, the difference not being significant. Body-weight was maintained at 5½ lb. on both rations. The amount of the tapioca ration consumed was slightly lower than that of the control ration.

When it was found that a high level of tapioca meal was proving satisfactory for laying stock it was decided to ascertain if it would be suitable for rearing chickens. Groups of cockerel chicks of the two crosses of Light Sussex with Rhode Island Red were used for the experiment [3], and tapioca meal, supplemented by fish meal, was incorporated in the mash at levels of 20 per cent. and 40 per cent., as a part replacement of the whole of the control mash, from hatching to the end of rearing at 14 and 15 weeks of age. The chickens were kept intensively until they were 8 weeks old, and thereafter were allowed access to grass runs.

The chickens fed on the ration containing 20 per cent. tapioca meal attained weights very similar to those of chickens fed on the control ration, varying in the different groups from 3½ lb. to 4 lb. With the higher level of tapioca meal there was a tendency for the final weights to be lower, a consequence perhaps of the slightly smaller amounts of food consumed.

The difference in food-consumption between the groups with the high level of tapioca meal and those on the control ration was not sufficiently great, either for hens or chickens, to suggest that the meal was unpalatable. The condition of the droppings showed the absence of constipating effects, and there were no indications of pasting of the mandibles, even though the addition of 40 per cent. tapioca meal gave a very finely divided mash.

Coconut-cake meal.—Coconut-cake meal is a food resembling bran in its general character, and it has a roughly similar chemical composition, particularly in respect of fibre. Local shortages of bran occurred in the early months of the war, and it was considered that coconut-cake meal might prove a satisfactory substitute. To test its suitability, it was fed to Rhode Island Red and Rhode Island Red × Light Sussex hens, housed in a semi-intensive house, with access to grass runs [4]. The birds had an evening feed of 1 oz. grain per head and had an unrestricted supply of

dry mash. The control mash contained 25 per cent. of bran and the experimental ration was of the same composition, except that the whole of the bran was replaced by an equal weight of coconut-cake meal.

At the end of a laying period of 24 weeks, in which the birds on the coconut ration ate rather less food than the control birds, the average body-weights of the birds on the two rations were identical, 5 lb. 10 oz., and the average yields of 73 and 74 eggs demonstrated the usefulness of coconut meal in replacing the whole of the bran in a laying ration. The physical condition of the droppings and the water consumption were normal throughout the test.

Substitutes for Protein Foods

Decorticated ground-nut meal.—Decorticated ground-nut meal (extracted) falls little short of fish and meat meals in its protein-content. It is widely used as a protein concentrate in rations for dairy cows and has been found quite satisfactory in pig-feeding if properly supplemented by minerals. Evidence of its use for poultry is rather scanty, but so far as it goes is favourable.

In the experiment on palm-kernel meal referred to above a further experimental ration was included in which the whole of the fish meal and dried skim milk, amounting to 8½ per cent. of the ration, was replaced by 10 parts of decorticated ground-nut meal and ½ part of salt. Reference has already been made to the additional ration in which this substitution was made in conjunction with the replacement of one-half of the wheat middlings by palm-kernel meal [1]. During a period of 36 weeks the former of these rations was equally as good as the control ration in respect of egg-production and of body-weight. The ration with the double replacement was not quite so good as the control ration, though no significant differences were observed.

Dried yeast.—The merits of dried yeast as a protein concentrate and as a source of vitamin B for poultry are now well known. The usual supplies of dried yeast originate as surplus yeast from the brewing industry, but saccharine fluids other than the water-extract from malt can be used as the medium for growing yeast. The material used in the experiments about to be described [5] was supplied by the Department of Scientific and Industrial Research, and consisted of a strain of the common yeast grown on 'black-strap molasses' from sugar-cane. It is referred to as 'fodder yeast' to distinguish it from the dried brewer's yeast, with which it was compared.

The two kinds of yeast were each used at a level of 12 per cent. (together with 1 per cent. salt) to replace the whole of the fish meal (10 per cent.) and part (3 per cent. of the ration) of the alfalfa meal in the control ration. The three rations were fed to groups of Rhode Island Red, Rhode Island Red × Light Sussex, and White Leghorn pullets, accommodated in an intensive house with a solid floor. A feed of 1 oz. grain per head was provided each evening and all groups had unrestricted access to their respective mash rations, given in a dry state.

No significant effect on egg-production was observed over a period of 24 weeks. All groups increased in body-weight, but the increase was

greater in the groups with brewer's yeast than with the control or fodder-yeast rations. On the other hand, mortality was highest in the brewer's yeast groups, but it is doubtful if this was due to more than chance. For war-time purposes it is evident that fodder yeast of the type used is a satisfactory source of protein for poultry feeding.

The birds used in these experiments were redistributed for further tests with other foodstuffs. In these new tests there was no important difference arising from their previous feeding, either as regards egg-production or body-weight, except that the birds fed previously on fodder yeast were inclined to be slightly but insignificantly lower in weight than either of the other sub-groups.

Steamed Potatoes

Bienko and Liersch [6], working with White Leghorns, found that 1·75 oz. of steamed potatoes daily, mixed with ground cereals, wheat, bran, and proteins, proved as satisfactory for egg-production and health as a ration without potatoes. Stahl [7] fed up to 2·5 oz. of steamed potatoes daily per bird without impairing egg-yield, hatchability, or food-utilization. Experiments carried out in Norway [8] showed that potatoes, given in addition to the necessary protein-containing foods, seemed to have no different effect on the laying capacity, weight-increase, and health of the fowl than other foods rich in carbohydrates. It was concluded that potatoes may be fed to laying hens to the extent of 15 per cent. of their food requirements.

When our investigations began, it was thought that it would be difficult to feed potatoes in excess of about 2 oz. per day to adult stock, on account of their bulk and the danger that birds consuming a large amount of food containing much water might not be able to provide themselves with sufficient nutriment to meet their daily needs for maintenance and production.

The original intention was to replace different portions of the maize in the mash by steamed potatoes supplemented with protein. The ratio of 4 to 1 in which the replacement was made represents, according to starch equivalents, the relative feeding-values of maize and potatoes. With every 4 lb. of potatoes was included 1·6 oz. of meat meal or its equivalent, to maintain the protein-content at the same level as in the rations not containing potatoes. On account of difficulties in obtaining straight foods the original intention of using potatoes as a specific replacement for maize meal had to be abandoned, and in the later stages the potatoes were used to replace different proportions of the whole mash.

The experiments on the feeding of steamed potatoes to chickens during rearing commenced when the birds were 8 weeks old; for cockerels they continued to the age of 13 weeks and for pullets to 14 weeks [9]. The birds had access to grass runs from the age of 10 weeks. Each hatch of chickens was divided at random into four groups, a control group to which no potatoes were fed and three groups in which maize meal, to the extent of 5, 10, and 15 per cent. of the total mash respectively, was replaced by steamed potatoes, supplemented with meat meal.

The final weights, adjusted by regression for differences in initial weight at 8 weeks of age, were not sufficiently consistent to determine an optimum level of potatoes, and on the whole there was no significant effect arising from the different rations. Even at the higher levels the inclusion of potatoes gave weights as satisfactory as those of the controls, and the health of the stock was in no apparent way affected.

The replacement of the lower level of maize meal by potatoes appeared to stimulate appetite slightly, the consumption of mash being a little higher than in the corresponding control groups. With the higher levels of steamed potatoes there was a real saving in mash, varying, for the highest level of potatoes, from 14 to 33 per cent. of that eaten by the control groups. The steamed potatoes constituted 17·5, 30, and 41 per cent. of the gross weight of food consumed by the three ration groups respectively.

In egg-laying experiments steamed potatoes were used mainly to replace part of the mash as a whole, although in the early stages, for the reason given above, the particular item replaced was maize meal. With White Leghorn pullets [10], the levels of steamed potatoes tested were 2 oz., 3 oz., and 4 oz. per day per bird, supplemented with protein and replacing one-quarter of these amounts of the control mash. The birds were given 1 oz. grain per head each day in addition to the wet mash and potatoes. No difficulty was found in getting the birds to eat 4 oz. steamed potatoes along with 4 oz. of grain and mash. The three levels of steamed potatoes constituted 32, 41, and 50 per cent. of the gross weight of food consumed. The saving of food was 10, 12, and 17 per cent. of the total amount of mash and grain consumed by the control birds.

Steamed potatoes were eminently satisfactory for egg production, since in all the potato groups the average production was slightly higher than that for the control ration. As regards body-weight, however, the averages adjusted by regression for differences in initial weight were significantly lower for the potato groups than for the control, the average difference being 4·7 oz. The potato groups did not differ significantly from one another.

Similar results were obtained with Khaki Campbell ducks [11]. In this experiment the levels of potatoes were 3 oz. and 4 oz. per day respectively. In addition, a test was made of the replacement of $\frac{3}{4}$ oz. of mash by $7\frac{1}{4}$ oz. of swedes or, when they were no longer available, $9\frac{3}{4}$ oz. of mangolds. There were no significant effects on egg-production, but the averages for the groups receiving roots were slightly below those for the control ration. In all cases there were losses in body-weight, but these were significantly greater in the groups getting steamed roots. These losses suggest that during the severe weather experienced the basic ration was not adequate to cover both the maintenance of body-weight and the requirements of egg-production at a level of 50 per cent. With swedes and the lower level of potatoes, the saving of food amounted to 13 per cent. of that eaten by the control, and to 18 per cent. with the higher level of potatoes. No difficulty was experienced in getting the ducks to eat the very bulky rations containing steamed roots, and the health of the birds remained good throughout.

In both these investigations the birds were allowed into grass runs. A later experiment was carried out with birds in laying-cages in a battery house. The amount of potatoes fed per head each day was progressively increased, in order to determine the limits of appetite to which the potato-feeding could be raised. In addition to potatoes, small amounts of green-food and hay-seeds were included in the mash. No grain was given. The daily consumption of potatoes averaged $5\frac{3}{4}$ oz. per head for the first 4 weeks, and in each of the next four periods of 4 weeks the average was $7\frac{3}{4}$ oz. Eventually a level of 8 oz. per head per day was reached. The average daily consumption over the whole period was $7\frac{1}{2}$ oz. per head. The average egg-production for the birds on potatoes was lower than that of the controls, but the difference was not sufficiently large to be regarded as significant. The average (adjusted) final weights, however, revealed a significant difference of 6 oz. to the disadvantage of the potato ration. The saving in mash was very considerable. Whereas the average consumption of mash per bird on the control ration was 47·1 lb., that for the potato ration was only 21·4 lb., a saving of nearly 55 per cent., which was made good by 78·9 lb. of potatoes, 4·6 lb. of hay-seeds, and a similar weight of green-food.

From the varied investigations on the feeding of steamed potatoes it is clear that they form a most useful substitute in war-time for a substantial part of the mash rations used in the rearing of chickens and the feeding of laying stock. No bad effects on health were observed, even when the potatoes formed as high a proportion as 40 per cent. in the later stages of chicken-rearing, or as high as 70 per cent. for laying stock kept intensively. The weights of chickens fed on potatoes were very satisfactory, but the body-weight of laying stock appeared to decline as the proportion of potatoes was increased. With laying pullets fed on potatoes, the egg-production of those kept semi-intensively was equally as good as for birds on the control ration, but for those kept in laying-cages and for ducks under semi-intensive conditions the egg-yield was not up to the level of the controls, although the differences were not large enough to be considered significant.

Dried Potato Meal

During the experiments with steamed potatoes and before rationing was introduced, the chief difficulties in the feeding of poultry were caused by the irregular and uncertain supplies of certain foods, particularly cereals and cereal by-products. The experience gained with steamed potatoes confirmed earlier impressions as to the usefulness of potatoes in forming a part of the carbohydrate portion of the ration and thus providing some relief when supplies of other foods were short. The building of factories for the production of potato meal gave promise of more abundant supplies of this foodstuff, with the advantage that it might be fed as a dry meal and without the main disadvantages of potatoes themselves, namely, bulkiness and the necessity for steaming and feeding as a wet mash.

The first consignment of potato meal was of good quality, but contained small dark flakes, presumably parts of the skin of the potato,

which the chickens pushed to one side and left uneaten. The next supply of meal was an excellent product, more uniform in appearance and floury in texture. Subsequent deliveries consisted of potato flakes, which often caked together in the bags, and before they could be used as a dry mash it was necessary to rub them through a sieve, a laborious process yielding a rather bulky meal, containing small flakes.

Considerable difficulties were experienced at times in obtaining the necessary ingredients for the basal part of the rations and some readjustments were necessary until the foods required were delivered.

Potato meal was fed to chickens [3] from the time of hatching until the end of rearing, which for cockerels extended to 14 or 15 weeks of age, and for pullets to the age of 20 weeks, when they were ready to be brought into the laying-houses. Up to the age of 8 weeks the chicks were housed intensively, but subsequently they had access to grass runs. Throughout the rearing period the rations were fed as dry mash. Potato meal, with additional protein to maintain the nutritive ratio at the same level in all rations, was used to replace 20 per cent. and 40 per cent. respectively of the control ration. One of the earliest features to be noticed in these experiments was the lower food-consumption of the groups with potato meal in their rations. The reduction was most noticeable with the ration containing the higher level of potato meal, the amount consumed being from 2 to 3 lb. less than that eaten by the control groups. With the lower level of potato meal the reduction was not so marked, but in every case the consumption was lower than for the control groups. The effect on final body-weight was not very conclusive, but in the majority of cases there was a decline in weight as the proportion of potato meal in the ration was increased.

The lower food-consumption of rations containing potato meal was also observed when this meal was fed dry to White Leghorn hens and Rhode Island Red × Light Sussex pullets. In each of these two experiments the levels of potato meal were 25 per cent. and 40 per cent., both fed dry, and a further level of 40 per cent., fed partly wet and partly dry. In all cases additional protein was provided to maintain the nutritive ratios at the same level as in the control ration. The birds were confined to the house and were allowed one ounce of grain per head daily. Over a period of 16 weeks the birds having 40 per cent. potato meal in dry mash consumed from 2½ to 6 lb. per bird less than the controls. Feeding at the higher level partly as a wet mash resulted in an improvement in the amount eaten, to a level above that for the group with the lower level (dry), but below that for the controls. After two months laying the body-weight of the White Leghorn hens reacted like that of the chickens, the birds with the highest level of potatoes having the lowest average weight, but towards the end of the experiment the onset of the moult resulted in a general loss in weight which appeared to mask any effect the different rations had produced. The pullets fed on the dry control mash gained in weight, whilst all the potato-meal groups lost weight. There was no significant difference among the three potato-meal groups, all of which differed significantly from the control. As regards egg-production the groups of hens did not differ significantly from one another, the average

being about 50 eggs per bird in 16 weeks. With the pullets, however, there were marked differences, the average for the controls being 58 eggs per bird, compared with 48 for the lower level and 41 for the higher level of potato meal fed dry. With the ration containing 40 per cent. potato meal, and fed partly as a wet mash, the average yield was 54 eggs per bird, i.e. it was not significantly different from the control ration.

In a further test with cross-bred pullets, kept semi-intensively and fed on wet mash and grain, there were only minor differences, in the amounts of food consumed between birds fed on the control mash and those with 25 per cent. and 40 per cent. of potato meal in their mash rations. After 20 weeks laying, the final weights differed but slightly from the average of $4\frac{1}{4}$ lb., and the egg-production showed no significant effect due to the potato meal.

With ducks kept semi-intensively there was no difficulty in getting the potato-meal groups to eat as much food, in the form of wet mash, as the controls. The levels of potato meal tested were 24, 42, and 60 per cent. in one experiment and 35, 50, and 65 in another experiment, the protein being maintained in all cases at the same level as in the control ration by the addition of protein concentrates. The daily food-consumption was $4\frac{1}{2}$ oz. mash and 1 oz. grain per head in all groups. The final body-weights for the potato-meal groups were slightly above those of the controls, but no significant effect due to the different rations was observed. On the other hand, the ducks previously fed on 4 oz. steamed potatoes per day had at the end of the test with potato meal a significantly lower weight than those previously on the control ration, or on the ration containing 2 oz. steamed potatoes per day. The potato-meal groups did not differ significantly among themselves in egg-production, but yielded more abundantly than the control groups. In the first experiment, lasting for 16 weeks, their average production was 55 eggs, compared with 40 for the controls, and in the second experiment, covering a period of 24 weeks, over 70 eggs per bird as against 54 for the controls. It is noteworthy that in this experiment ducks previously fed on steamed swedes and mangolds laid significantly more eggs than those previously fed on the control mash or on steamed potatoes. The lowest yield was from ducks which had been given 4 oz. steamed potatoes per head daily in the previous experiment.

As far as investigations have so far proceeded, chickens reared on rations with different levels of dried potato meal have not shown in subsequent laying-tests any outstanding effects due to their different rearing rations.

Town Food Waste

The collection of edible refuse from householders, hotels, canteens, and other sources, and its conversion into a dry meal for feeding to stock has been undertaken on a considerable scale in many of the larger towns. This 'Town Waste' has assumed some considerable importance in poultry-feeding, and forms part of the standard 'Balancer Meal' supplied to domestic poultry keepers.

In our tests [3] the Town Waste was fed at different levels to chickens,

from hatching to the marketing stage in the case of cockerels, and to the laying stage for pullets, to laying pullets under various conditions and to laying ducks. Most of these tests were carried out in conjunction with the tests of potato meal and tapioca meal.

In spite of the unusual dark colour which it imparts to the mash and its penetrating, unpleasant smell, no difficulty was found in getting chickens to eat Town Waste in a dry mash at levels of 30 per cent. and 50 per cent. of the total ration. On the other hand, laying pullets not familiar with this food at first showed little relish for it in the dry form, and in general ate less food than those on the dry control mash. The most striking difference was with birds in a laying-battery fed on a ration containing 70 per cent. of Town Waste, the amount of mash taken per bird being 10 lb. less than the average of 65 lb. for the controls over a period of 32 weeks. When Town Waste was included in a wet mash and supplemented with grain, as it was for laying ducks and cross-bred pullets housed semi-intensively, the food was consumed as readily and to an equal extent as the control ration.

Rations containing up to 30 per cent. of Town Waste had on the whole no different effect on body-weight than had the control rations, either for chickens or for laying stock. When Town Waste constituted 50 per cent. or more of the ration, however, there was a significant fall in final weight, both with chickens and laying pullets, but with ducks the difference was less marked.

The general result was that the birds fed on Town Waste produced fewer eggs than those in the control groups. The ducks provided an exception, for with them the feeding of Town Waste at levels of 50 per cent. and 70 per cent. of the wet mash led to a higher egg-production than that resulting from the feeding of the control mash. With laying pullets the lowering of production was not very marked when the rations contained 25 per cent. of Town Waste. Where the level was 50 per cent. or over, however, the fall in egg-yield over periods varying from 16 weeks to 32 weeks in different tests ranged from 11 per cent. to 38 per cent. below that of the corresponding controls.

Concerning health, the only outstanding feature was the development of leg weakness in 3 ducks from a group of 40 birds fed on a mash ration containing 70 per cent. of this meal. The trouble occurred during inclement weather, and it may have been a coincidence that the three cases occurred with the same ration. The birds made good recovery without special treatment.

Birds reared on rations with different levels of Town Waste have not, up to the present, shown any outstanding differences in subsequent laying experiments.

Controlled Feeding of Pullets during Rearing

In 1939 an experiment was carried out to discover the effects of imposing restrictions on the food-consumption of chickens from the age of 2 weeks onwards [12]. For the experimental groups the mash-hoppers were closed during part of the day, but they received morning and evening the same *ad lib.* grain-feeding as the controls. This method had

the advantage of simplicity in application, but it failed to bring about any considerable reduction in total food-consumption, or any apparent stimulus to more active grazing. The net effect indeed was merely to cause a readjustment of the proportion of mash to grain in a relatively unchanged total food-consumption. The groups differed nevertheless to a small, but significant, extent in average body-weight at the end of the rearing-period, the unrestricted groups being 2·5 oz. per bird heavier on the average than the restricted groups.

It was clearly necessary to devise some more effective method of reducing total food-consumption, and consequently in the following year the basis of the experiment was substantially modified. It was felt that any cut in the early stages of rearing was probably undesirable, and in any case could only be negligibly small in terms of food economy. The restriction of food was not introduced, therefore, until the pullets were 10 weeks old. The method of restriction adopted was to provide to different groups 85 per cent. and 70 per cent. respectively of the amount of mash consumed per bird by the control group on the previous day, and the same amount of grain per head as that eaten by the control group. This procedure, though laborious, was successful, and in different replications the total mash consumed up to 22 weeks of age differed only in the first place of decimals from the levels of 85 per cent. and 70 per cent. The control groups consumed approximately 12 lb. mash and 8 lb. grain per bird in the 12 weeks.

Over the range of mash-restriction observed, there was a fall in final weight between the unrestricted and restricted groups. The extent of the difference varied in different hatches, but for the groups with the more severe restriction it was almost twice as great as when the amount of mash was curtailed by 15 per cent. With the heavier restriction, the final average weights varied between 3 lb. 13 oz. and 4½ lb., whilst those of the controls varied from 4 lb. 5 oz. to 4 lb. 10 oz.

The investigation is being continued throughout the current (1941) rearing season. Owing to the national restrictions on the feeding of grain to poultry, the birds are being fed solely on mash, and the restrictions of mash, though not of total food, are in consequence less severe and are aimed at 90 per cent. and 80 per cent. of the food eaten by the controls.

In all these experiments the pullets at the end of rearing have been transferred to individual cages in a battery or to an intensive house, where they have all been fed alike during a test of their laying capabilities.

The pullets reared in 1939 with no restriction in feeding produced 157 eggs per bird during a period of 48 weeks, whilst the average yield from those with access to mash at limited periods during rearing was nearly the same, at 155 eggs per bird. In final body-weight and average egg-weight also, the differences in favour of the unrestricted groups were similarly negligible.

With the pullets reared in 1940 the differences in egg-production, final body-weight, and egg-weight were again negligible. Production in the various groups during a period of 36 weeks differed only to a small extent from the average of 117 eggs per bird, the groups with unrestricted feeding during rearing producing very slightly below this

value. The average final body-weights centred round 6¼ lb. and showed no significant effects due to the different methods of feeding during rearing.

The restriction of mash has not led to any improvement in stamina, so far as this may be judged by mortality rates. During rearing there was no marked difference between the unrestricted and restricted groups. With the pullets reared in 1939 there was only a small difference in mortality during the year of laying, what superiority there was lying with the unrestricted groups. Pullets reared in 1940, however, showed a striking difference, indicating a possible danger to health when food is too severely restricted.

Controlled Feeding of Laying Pullets

Experience at the Institute with laying pullets kept in individual cages in a laying-battery on a standard balanced mash fed *ad lib.* has shown that the average daily consumption has been about 4½ oz. per bird, or slightly over. In our first investigation into the restriction of food for laying pullets in a battery it was assumed that the control birds, White Leghorns, would consume daily 4·6 oz. of mash per bird. The restriction of food to other groups was carried out by three methods. In the first, the amount was controlled by weight, a ration of 3⅞ oz. per head per day being provided in two feeds. Under practical conditions the weighing of food to individual birds is laborious, and in this experiment the food was measured by volume after the first few days with periodical weighings to provide a check. The average daily consumption worked out at a slightly lower level than that indicated above. In the second method the food was restricted by closing the hoppers for certain periods during the day. In the short days of winter the hoppers were closed from 10 a.m. to noon, and as the days lengthened the period of closing was increased until in the later stages of the experiment they were kept closed from 9 a.m. to 1 p.m. and from 2 p.m. to 5 p.m. The third method of restricting mash consumption was based on the supposition that the provision of considerable bulk early in the day would induce physical satisfaction and limit the capacity of the birds for further feeding. At the outset the bulk was provided by feeding grain (3 oz. per bird in the dry state) which had been soaked for 24 hours. The grain absorbed about half its own weight of water. Mash was withheld until the grain had been consumed. This amount of grain proved too high and was reduced to 2 oz. dry weight.

The feeding of soaked grain was discontinued after 24 weeks on account of the national restrictions introduced on the feeding of grain to poultry. During this period the average consumption per bird was 24·6 lb. grain and 21·5 lb. mash, compared with 47·1 lb. of mash with *ad lib.* feeding. In total food, therefore, there was little saving. Egg-production at 83 eggs per bird was 8 eggs below the average with feeding *ad lib.*, and the final (adjusted) body-weight, 65 oz., was only 3 oz. lower than that of the controls, both differences being insignificant.

During the 32 weeks of laying by the remaining groups the controls consumed 65·3 lb. of food, and the saving in mash by time restriction and amount restriction were respectively 16 per cent. and 21 per cent.

The average egg-production in the three groups was 122, 118, and 101 eggs per bird respectively. There were substantial differences in final body-weight, the controls averaging 66 oz. per bird and the two restricted groups 58 oz. (time) and 54 oz. (amount).

From the results obtained with White Leghorns in this experiment comparative figures are presented in Table 1 showing the total egg-production and total final live-weight of 100 birds restricted to 3·7 oz. food per day for a period of 32 weeks, and the corresponding values when the same total amount of food was fed *ad lib.* and by restricting the times of feeding.

TABLE 1. *Comparison of Results from Different Methods of Feeding the same Total Amount of Food for 32 Weeks*

	Restriction to 3·7 oz. per day	Ad lib. *feeding*	*Restricted times of feeding*
Number of birds	100	79	94
Total food (cwt.)	46·2	46·2	46·2
Eggs, dozens	840	803	927
Total final live-weight (lb.) . .	335	324	346

There appears to have been some advantage in restricting the food-consumption, more particularly where it was effected by closing the hoppers at certain times of the day.

A further experiment on controlled feeding is still in progress. The work is being carried out with Light Sussex × Rhode Island Red pullets in an intensive house provided with a solid floor and sun parlours. Previous experience indicated that the control groups fed on dry mash without any restriction would consume about 4½ oz. of food per head per day. The experimental groups have been provided daily with definite weights of food, 3·82 oz. and 3·37 oz. per head, representing savings of 15 per cent. and 25 per cent. respectively. The results after 20 weeks' laying show no significant effect on body-weight, but in egg-yield there is already a striking difference between the control groups (62 eggs per bird) and the groups with the lower amount of food (50 eggs per bird). There is as yet no noticeable deterioration in egg-production in the groups receiving the intermediate amount of food.

Rearing of Geese

An experiment was carried out to investigate the possibility of rearing geese for the Christmas market by grazing for the whole period, as compared with giving supplementary food for the last 4 weeks and 8 weeks respectively [13]. For the first 6 weeks the goslings were reared on a proprietary chicken mash and thereafter maintained themselves by grazing in the poultry runs. At 26 weeks of age a third of the geese were given supplementary food twice a day for 8 weeks until the time of marketing. The remainder continued to graze, one-half of them until marketing and the other half for 4 weeks, after which they were given supplementary food for the remaining 4 weeks.

The results obtained showed that even in a difficult season with a long period of drought it is possible to produce marketable geese by grazing alone. The condition of the birds would not, however, be regarded as satisfactory in normal times when ample supplies of food are available. The birds had yellow flesh, were stubby and not in such good condition as trough-fed birds. They weighed 7 lb. 9 oz. on the average, compared with 9 lb. 12 oz. and 9 lb. 3 oz. for the other groups.

The feeding of supplementary food for 4 weeks gave practically the same results as when the feeding-period extended to 8 weeks. The effect of feeding after grazing was an immediate and rapid increase in weight. The high rate of gain persisted only for a time, however, probably on account of a gradual fading away of the stimulus to appetite.

The overriding influence of seasonal conditions for a good supply of grass cannot be too strongly emphasized, and the successful use of grass for geese with or without a limited supply of food calls for good judgement and skilful management.

Summary and Discussion

Much of the work summarized in this paper represents little more than a preliminary survey of the problems involved, designed to give quick guidance as to the possibilities of effecting war-time adaptations of poultry-feeding practice to prevailing conditions. What seem to be the more urgent lines of inquiry are being followed up and the investigations extended to embrace other means of reducing the dependence of poultry upon foodstuffs in respect of which they compete for supplies with other live stock or the human population. In the work already carried out there are certain points to which attention may be drawn.

(1) When used as substitutes for concentrated starchy foods palm-kernel meal (extracted) and tapioca meal, both up to levels of 20 per cent. of the mash, and coconut meal at 25 per cent. proved very satisfactory. With a level of 40 per cent. of tapioca meal there was a tendency towards a lower body-weight in the rearing of cockerel chickens.

(2) As alternative sources of protein, decorticated ground-nut meal, brewer's yeast, and a fodder yeast were found to be useful ingredients in rations for laying stock.

(3) The extent to which steamed potatoes may be fed to poultry has gone beyond expectations, and has brought about no marked change in egg-production, except for a slight lowering with ducks and pullets kept intensively, though body-weight was not quite maintained in the case of laying stock. The period of 6 weeks during which potatoes were fed during rearing may have been too short for such an effect to become noticeable.

(4) One of the chief difficulties experienced with potato meal was the lower food-consumption when it was fed dry. There was little difficulty in maintaining a satisfactory consumption when it was fed as a wet mash; both body-weight and egg-production were then satisfactory, particularly in the case of ducks.

With potato meal and Town Waste there have been difficulties in

obtaining supplies and considerable variation in the type of product received. The process of manufacturing potato meal is apparently not yet sufficiently stabilized to result in a food reasonably uniform in texture and quality from one consignment to the next.

(5) Town Waste, from its nature, must be expected to show considerable variation in composition. The supplies used in these experiments were not typical of meal made from kitchen waste alone, and it is certain that other forms of waste, particularly fish, were included in the meal.

A lower food-consumption was experienced in feeding Town Waste as a dry food to laying stock, but chickens brought up on this food consumed it readily in a dry state throughout the rearing-stage. The difficulty was solved, as with potato meal, by feeding it as a wet mash. The inclusion of Town Waste as 30 per cent. of the mash produced no significant effect on body-weight and only a slight fall in the egg-production of pullets, but an increase in that of ducks. At levels of 50 per cent. or more, body-weight was adversely affected and the egg-yield of pullets reduced.

(6) The methods adopted to control the amounts of mash consumed during rearing have, up to now, led to a lowering of the body-weight of pullets at maturity. This disadvantage does not, however, appear to have affected performance during the laying year.

(7) The work on the controlled feeding of laying stock is in its early stages, but so far as it has gone it suggests that feeding *ad lib.* under intensive conditions is not the most efficient method of utilizing food (a primary consideration in war-time), and that the more severe restrictions adopted do not supply sufficient nutriment to maintain both body-weight and egg-production at the levels reached with feeding *ad lib.* Further research into this problem should give useful information on the food-requirements of laying birds for maintenance and production.

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TOBACCO RESEARCH IN CANADA

N. T. NELSON

(*Chief of Tobacco Division, Central Experimental Farm, Ottawa, Canada*)

TOBACCO research in Canada is centralized in the Dominion Department of Agriculture, and the major responsibility for this work devolves upon the Tobacco Division of the Experimental Farms Service. Certain phases of research, such as investigation of tobacco diseases and insect control, are conducted co-operatively with Science Service Divisions, including Botany, Bacteriology, Chemistry and Entomology. Some tobacco soil investigations are being undertaken in co-operation with the Chemistry Department of the Ontario Agricultural College located at Guelph, Ontario.

The Dominion experimental stations concerned with tobacco investigations are conveniently located in the principal tobacco areas of Canada. The head-quarters staff of the Tobacco Division is at the Central Experimental Farm, Ottawa, about midway between the tobacco-producing areas of Quebec and Ontario. In the province of Quebec the experimental station located at L'Assomption gives special attention to the cigar, aromatic pipe, and flue-cured types grown commercially in that section. The principal station of Western Ontario is at Harrow, where the problems of burley and dark tobaccos are investigated. This station is equipped with laboratories for the study of tobacco diseases and insects. The Tobacco Sub-station at Delhi, Ontario, is concerned exclusively with flue-cured tobacco. The Summerland Station renders service to the growers of British Columbia. The work of each station is specialized to suit the problems of the kind of tobacco grown in the vicinity.

Within the limited scope of this paper, it will be possible only to indicate briefly some of the more outstanding results obtained in recent years. The list of projects enumerated below shows that all investigations are planned with a view to improving the quality and yield of the tobacco crop. Special emphasis is laid on obtaining information that may be readily applied in farm practice. In this way experimental findings are put to practical use as soon as the results justify it. The applied aspect, accordingly, is given preference over the purely fundamental, although the latter is constantly being sought.

Tobacco research conducted by the Tobacco Division and associated experimental stations includes (1) agronomy and soils, (2) physiological investigations, (3) genetics and varietal improvement. The following list of projects indicates the scope and diversity of work now under way: crop-effect studies (including brown root-rot); tobacco mosaic; black root-rot; stripping and grading; soil investigations (type, nutrient levels, &c.); topping and suckering; chemical composition, including carbohydrate and nitrogen metabolism; harvesting methods; steaming tobacco into case; insect pests; production, harvesting, and storage of seed; relation of temperature and humidity to curing; the 'burning' quality

of tobacco; cover, green manurial, and rest crops for tobacco; fermentation; genetical and cytological studies; seed-bed construction and management; effects of climatic factors; spacing of plants in the field; rotations; varietal tests; methods of applying fertilizers; use of barnyard manure and muck in tobacco fertilization; sources of nitrogen, phosphorus, and potassium in fertilizing the crop; quantitative requirements of the tobacco plant for nitrogen, phosphorus, and potassium; importance of essential minor and trace elements; organic *v.* water-soluble nitrogen; fertilization of the rye cover-crop; sulphur, calcium, magnesium, and chlorine studies; importance of soil organic matter in tobacco soils; nutritional studies under greenhouse conditions.

Extensive field experiments, with all treatments at least in quadruplicate on approximately $\frac{1}{40}$-acre plots, are in progress to test fertilizers, rotations, varieties, cover and green-manurial crops. Pertinent field records of growth, maturity, and general plant-response are taken to supplement the final record of yield per acre and the quality, which is based on careful assortment of the cured leaf into various commercial grades. Each treatment can thus be evaluated, and the practical significance of the results obtained may be readily outlined to the grower. Results of a more fundamental nature are thoroughly tested under laboratory and greenhouse conditions.

Agronomy and Soils

Comprehensive field tests with fertilizers, designed with a view to their practical application, have been in progress for many years. For the past ten years a special advisory tobacco-fertilizer committee of agronomists has met annually to review the results of these experiments and to outline fertilizer recommendations to the growers. These recommendations embody the more important results obtained from field tests conducted at the experimental stations, in addition to a number of co-operative tests on commercial farms representing various soil types.

Tobacco fertilizers.—The growth of the plant in the field and ultimate leaf-quality of the tobacco produced are largely dependent on the application of a well-balanced fertilizer mixture suitable to the type of leaf grown. In Canada the selection of an appropriate fertilizer is nearly as important as the choice of a field for successful commercial production. Each of the major types of tobacco grown requires somewhat special fertilizer treatment to promote the most favourable development of leaf-quality desired in the manufacture of various tobacco products.

When choosing a fertilizer it has been found necessary carefully to consider special factors such as soil type, natural productivity, nutrient deficiencies, manure applications, and general practices in soil-management. Winter cover-crops and rest-crops have been found essential to maintain the humus of the soil and to conserve fertilizer not taken up by the flue-cured crop. A two-year rotation, tobacco and rye, has given excellent results. The rye is sown immediately following the harvesting of the tobacco, and is disked down the next summer when ripe. The latter operation is responsible for the self-seeding of another crop of rye, which serves as a cover-crop and protects the tobacco land from erosion

by wind and water, besides supplying active organic matter on being ploughed under the following spring. Soil fertility is thereby conserved because the bare land is exposed to weathering conditions for the shortest possible time. Deficiencies of essential elements required by the plant, or ploughing under cover or other leguminous crops, may make it desirable to increase the proportion of the deficient nutrients or reduce the nitrogen in the fertilizer mixture. On fields tending to produce slow-ripening tobacco, the condition may in many instances be corrected by increasing the proportion of phosphoric acid and potash in the mixture and reducing the rate of application. In other cases where nitrogen and potash are not limiting factors, earlier maturity may be obtained by simply increasing the phosphoric-acid content and applying the mixture at the ordinary rate per acre.

Since soil reaction is an important factor in determining the prevalence of black root-rot, lime must be applied with caution and only after a test has indicated the need for it.

Sources of Materials

Nitrogen (N).—It is advised that approximately one-quarter of the total nitrogen be derived from high-grade organic materials of plant or animal origin. At least one-quarter of the total nitrogen (one-fifth in cigar-tobacco fertilizers) should be in the form of nitrates. The remainder of the nitrogen may be derived from standard water-soluble materials.

Phosphoric acid (P_2O_5).—Derived from superphosphate or other easily soluble phosphates.

Potash (K_2O).—Owing to war conditions, it has been deemed necessary to limit the potash-content to 10 per cent., and to permit a maximum of 3 per cent. and a minimum of 2 per cent. of chlorine (Cl) in fertilizers for tobacco. Chlorides commonly are introduced into tobacco fertilizers when the muriate instead of the sulphate form of potash is added. In fertilizers for cigar tobacco it is desirable that chlorides be reduced to a minimum in order to obtain a good burning tobacco. The chlorides may be reduced by omitting muriate of potash from the mixture; sulphates may be lowered substantially by substituting urea for sulphate of ammonia and using, in addition, the higher grades of superphosphates or other soluble phosphatic materials of high analysis.

Magnesia (MgO).—Owing to the occurrence of magnesium-deficiency in certain tobacco soils it is recommended that a high-grade dolomitic limestone, analysing at least 19 per cent. of magnesia (MgO), be used as a filler in tobacco fertilizers.

Lime (CaO).—Since most tobacco fertilizers now manufactured contain some lime as a filler, additional applications of lime should not be made unless soil tests indicate the need.

Analyses of Mixtures and Rates of Application

Fertilizers for flue-cured tobacco.—Under average conditions apply 800 to 1,000 lb. per acre of a 2–10–8 mixture. Where potash levels in the soil are definitely low the potash should be increased by using a 2–12–10 fertilizer. Where slow maturity has been experienced an appli-

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cation of 700 to 800 lb. per acre of a 2–12–10 mixture will tend to hasten maturity and better suit such conditions. Although a 2–12–6 and a 3–10–8 are not recommended for general use, there are special conditions under which these mixtures may be used to advantage.

The fertilizer when applied in the row should be thoroughly mixed with the soil a week before transplanting. Recent experiments have demonstrated the advantages of applying the fertilizer in bands 4 to 6 in. on each side of the row and slightly below the level of the root-crowns at the time of transplanting.

Fertilizers for burley tobacco.—On sandy loam and gravelly loam soils use a 4–8–10 mixture. Use a 2–12–6 or a 2–12–10 mixture on clay loam soils. Apply 500 to 1,000 lb. per acre and thoroughly mix with the soil a week before transplanting. Recent experiments have demonstrated the advantage of applying fertilizer in bands on each side of the row.

Fertilizers for dark tobacco.—For dark tobacco 500 to 800 lb. of a 4–8–6 mixture per acre has given good results. Under certain conditions more potash may be used to advantage. Best results have been obtained from drilling the fertilizer in the row.

Fertilizers for cigar tobacco.—With 10 to 12 tons of manure, apply 800 to 1,200 lb. per acre of a 5–8–10 or 5–8–7 fertilizer mixture. Without manure, the fertilizer rate of application should be increased to 1,200 and 2,000 lb. per acre.

Fertilizers for pipe tobacco.—Large varieties: 800 to 1,000 lb. per acre of a 5–8–10 mixture. Small varieties: 600 to 800 lb. per acre of a 5–8–10 mixture.

Tobacco soils

Analysis of tobacco soils has been closely allied to the physiological work of the Tobacco Division. Although tobacco will grow on a wide variety of soils, the successful production of good-quality leaf requires the selection of special soil types for each type of tobacco. For this reason soil surveys have been a practical necessity to the industry in Canada. County soil surveys have been made in the tobacco districts as a co-operative project with provincial agencies. Several series of all the characteristic soil types have been subjected to a complete chemical and mechanical analysis, and these data have been used as a standard of comparison in all subsequent soil diagnoses for prospective growers. Soil analysis is also conducted in connexion with the fertilizer plots at the Central Farm and on the branch stations. Some of the projects studied are: the building up of a potash reserve in the soil; the phosphate-fixation problem in relation to the continuous application of phosphatic fertilizers over a period of years; the maintenance of organic matter in light sandy soils; appraisal of the rapid-test methods of soil analysis.

Physiological Investigations

The physiological work of the Tobacco Division has been in progress since 1933. It may be divided broadly into three sections: mineral investigations, carbohydrate and nitrogen metabolism, and nutrition.

Certain projects under these headings have been conducted over a period of several years, being repeated and revised with each new crop. Some of these are still in operation.

Mineral absorption.—The mineral investigations have been carried out in connexion with the extensive fertilizer trials at the Central Farm in Ottawa and at the branch farms. One of these trials, the 'quantity of potash' series, consists of three treatments in which progressive increments of potash in the form of sulphate are used in the basal formula. There are three treatments, each applied on six plots. The results of several years of experiment indicate that variation in the potash fertilizer has a greater and more consistent effect on the quality of tobacco than on the yield. Samples of cured and graded tobacco from these plots were subjected to a fairly complete mineral analysis. The data were correlated with the seasonal rainfall and with the analysis of soil from the plots where the tobacco was grown, and have been used in planning further fertilizer experiments and in determining fertilizer practices for the growers.

A similar experiment was conducted in connexion with another fertilizer trial, the 'quantity of phosphorus' series. Experimental results over several years have indicated in this case that progressive increments of superphosphate in the fertilizer of the basal ration are responsible fo direct increases in both yield and quality of the leaf produced. There were four treatments in the experiment and each was applied in quadruplicate. Here again samples of cured and graded leaf and soil were analysed, and the results used in the interpretation of the mineral absorption of tobacco-leaf as influenced by variable phosphatic fertilizer.

The main investigation, however, in connexion with fertilizers and the mineral economy of tobacco is known as the mineral-absorption project. The purpose of this experiment was to make an observation of the rates of mineral absorption and a study of some of the factors affecting those rates, in order to ascertain how much of the fertilizer is used by the plant, and when the plant requires each mineral nutrient. The project was begun in the summer of 1935 with cigar tobacco, grown on the fertilizer plots of the Tobacco Division at the Central Experimental Farm. All plants taken for samples were normal, average plants, secured from a standard fertilizer plot which had received the equivalent of 2 tons per acre of a 4–4–5 fertilizer mixture, and all the normal cultural treatments. The experiment was started at the time of transplanting and continued throughout the season until harvesting. Samples were selected at regular intervals so as to be representative of the various characteristic stages of plant-growth.

All plants were divided into various portions, such as bottom leaves, middle leaves, top leaves, tops, and stalks, and each separate portion was subjected to a fairly complete mineral analysis. In this way a complete picture of the season's growth was obtained. Measurements and weights of the growing plant were also recorded so that the final results could be expressed biometrically as well as on a percentage basis. The experiment was started on a somewhat modest scale in 1935, but since then it has been repeated for several seasons with modifications and additions,

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and finally has assumed considerably larger proportions. First the number of critical stages of growth was increased. In addition, the experiment was extended to include observations on the cultural practice of topping and, later, on the practice of suckering. A detailed growth-analysis has also been included. The original experiment was conducted on cigar tobacco, but the project has since been expanded to include a corresponding experiment with flue-cured tobacco. This has involved a study of the priming method of harvesting and its effect on mineral absorption. Finally, burley tobacco has been investigated similarly. Root-development and the analysis of seeds have completed the picture. This project has provided an extensive volume of data which are particularly useful in the determination of the effect and relative benefit of fertilizer and cultural practices.

Carbohydrate metabolism.—Another extensive physiological project of tobacco research is the investigation of carbohydrate metabolism. This work has been closely associated with the curing of tobacco. An initial survey was made to determine the importance of carbohydrates in relation to the quality of flue-cured leaf. After it was found that soluble sugars play an important role in the proper carbohydrate-balance necessary for good quality in this type of leaf, it was decided to investigate the flue-curing process in order to determine the conditions responsible for setting up this important balance. Samples of normal leaf were taken from the kiln at regular intervals during the curing process and analysed for carbohydrates. It was discovered that enormous changes occur in the chemical composition of the leaf, but the changes are very consistent, and certain general trends were found to be quite characteristic. The next step was to trace the development of carbohydrates in the growing plant until the time the leaf enters the kiln. The great variety of factors affecting the photosynthetic process has rendered this phase of investigation, which is still in progress, extremely complex. Further work has shown that carbohydrates in fully cured leaf, which are so important in the chemical constitution of flue-cured tobacco, do not assume an important status in the quality determination of the air-cured types. Air-curing apparently induces a different type of senescent respiration, with the result that the cured product has a totally different chemical constitution from that of flue-cured tobacco.

Nitrogen metabolism.—Since nitrogen as a nutrient is considered to be so important in determining both field-growth and leaf-quality, a study of this element in relation to its behaviour within the plant is in progress. By far the greater part of the nitrogen found in fully matured leaves of cigar tobacco is absorbed by the plant during the growth-stage just prior to topping. Topping at the early-bloom stage, followed by suckering, had the effect of increasing the total-nitrogen content, and at the same time of delaying the maximum nitrogen accumulation two to three weeks. Proteins, nicotine, and nitrates are the chief forms of nitrogen found in the cigar-tobacco leaves. Ammonia, amides, amino-acids, and peptides are apparently transient metabolites, important in the synthesis of protein and possibly non-nitrogenous substances.

The changes in the protein nitrogen and the soluble nitrogen effected

by topping and suckering probably indicate the phenomena of both anabolic and catabolic processes. In the case of nicotine there is a well-defined ontogenetic development involving the progressive accumulation of nicotine in the maturing leaves accompanied by a decreased rate of protein synthesis, the rapid diminution of nicotine in the seeds on approaching maturity, and ultimately, the definite and conspicuous absence of nicotine in the mature tobacco seeds.

The role of nitrate nitrogen appears to be more important than is usually realized. Forty to seventy per cent. of the soluble nitrogen of the leaf is nitrate. Its accumulation in the leaves reached a maximum one to two weeks after the plants had been topped and suckered at the time of harvest of the main crop at Ottawa. Its behaviour suggests that the leaf-nitrate may be utilized for protein synthesis, especially at times when the supply of soil nitrate and ammonia becomes exhausted.

Small amounts of ammonia, amides, amino-acids, and peptides are found in tobacco leaves. These substances are extremely active metabolites and their functions are inter-related. The higher concentration of these metabolites in the younger leaves suggests greater absorption of ammonia from the soil and a higher metabolic rate. The small and changing amounts of ammonia in the leaves apparently depend on the fluctuating supply of ammonia from the soil resulting from the variable soil and weather conditions during the growth-period, and the relative rate of assimilation. The leaf-amide is mostly asparagine, although glutamine is also present. As was expected, there is evidence to indicate that amide syntheses succeeded increases of ammonia in the leaves of the topped plants, but not of the untopped plants. These apparently transient metabolites are physiologically significant, for they seem to be important in the synthesis of nitrogenous and non-nitrogenous substances during the period of leaf-maturity.

At the same time, it is of practical significance that the accumulation of nitrate in the leaves was at its maximum and the protein at its minimum at harvest time. A high nitrate-content improves the burning quality and a low proportion of protein is associated with the better grades of cured and fermented cigar leaf.

Nutrition studies in sand culture.—Nutrition studies have been conducted under controlled conditions in sand culture in the greenhouse, the object of this investigation being to determine the optimum nutritional requirements of the tobacco plant and the significance of the major nutrient elements. A flue-cured variety, White Mammoth, has been used in this work, since the sand culture is more comparable to the light sandy soil of the flue-cured areas than to that of other tobacco types, and the information gained from the study will probably be most applicable to this type. It was intended that the information gained from this investigation would make a direct contribution to our knowledge of the nutritional requirements of the plant and assist in the proper interpretation of data collected from fertilizer experiments in the field.

Each plant was grown in a 3-gallon glazed pot and supplied with 1 litre of nutrient solution daily. A multiple-salt system of nutrient

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solution was used, making it possible to vary the relative concentrations of the six major ions, namely, Ca, Mg, K, NO_3, SO_4, and PO_4. This method of varying each ion separately makes it possible to study the physiological significance of each ion and the metabolic influence of one ion upon another.

In the first series a general investigation was made by varying each ion over a wide range of concentration. In the next series the concentrations of NO_3 and Ca were varied closely around the levels which had given best results in the first series, and a detailed study was made of Mg and SO_4, which had depressed growth at high levels in the first series. In the next series the concentrations of Mg and SO_4 were held constant at a level within the optimum range, and a detailed study was made of the other four major ions, namely, Ca, K, NO_3, and PO_4.

The results of this work strongly indicate that the optimum concentration of nutrient elements cannot be determined within narrow limits. Good growth has been produced over a fairly wide range of mixtures, provided the total supply of essential elements was adequate. The plant's power of adaptation apparently enables it to grow over a wide range of concentrations of nutrient elements. However, it seems possible to determine the optimum concentration range of each element.

Results obtained indicate that the NO_3-ion has the greatest influence upon growth. There is a close correlation between the ability of the plant to utilize high concentrations of NO_3 and the relative concentrations of the cations (Ca, Mg, and K). At low NO_3-levels the distribution of the cations is of little significance in its influence upon growth; but as the NO_3-level increases, there is an increase in the importance of the relative cation proportions as regards their influence on the effectiveness of the NO_3-ion to produce high yield. Consequently, a favourable balance of the cations should be maintained.

In these experiments the NO_3-supply was the factor which exerted most influence on the moisture-content of the leaf-tissue, since the proportion of water in the leaves increased with increased NO_3-supply. The relative proportions of SO_4 and PO_4 did not appear to have any definite influence on the degree of moisture in the tissue. Treatments high in K produced leaf-tissue higher in water-content than did treatments high in Ca. In contrast, a higher percentage of dry material in the leaf-tissue was produced by an increase in Ca in the nutrient solution.

To study the influence of one ion on the accumulation of another in the plant-cells, the plant-tissue was divided into two fractions, the stems and the leaves, and each fraction was analysed for the total content of the six major nutrient elements. The results show that the factor exerting primary influence on the accumulation of an element in the tissue is the concentration of that element in the nutrient solution. It was shown further that the accumulation of an element may be directly or indirectly influenced by the concentration of other elements in the nutrient solution.

Plant hormones.—Experiments were conducted to make a quantitative and qualitative study of the effect of hetero-auxin on the growth of tobacco seedlings. The seedlings were grown in pots under normal

greenhouse conditions. Several methods of applying the hormone were tried: (1) the full amount of hetero-auxin was added to the soil in aqueous solution at one application; (2) aqueous solutions over a range of dilutions were added to the soil at 3-day intervals; (3) the hetero-auxin was dusted on the seed prior to planting, over a wide range of concentrations.

In general, it was found that the lowest concentrations of hetero-auxin produced no observable results. A higher range of concentrations accelerated the growth of both tops and roots. A still higher range resulted in inhibition of growth.

Genetics and Varietal Improvement

The plant-breeding programme aims fundamentally at varietal improvement. It includes a genetical analysis of characters of economic significance, the hybridization and development of new strains, the standardization and classification of segregating populations, and the varietal testing of new introductions.

The genetical analysis of characters of economic significance began with the establishment of a large number of stock cultures displaying such characters as resistance to black root-rot; susceptibility to black root-rot; resistance and susceptibility to mosaic; chlorophyll-deficient strains; early, intermediate, and late strains; lanceolate, broad, and petiolate leaf-bases; carmine, pink, and white flower colours, &c. In order to establish as complete a collection as possible recourse was made to a *Nicotiana triplex* selection developed by Dr. R. E. Clausen of the University of California. This strain embodied the complete genoms of *N. tabacum* (*purpurea*) and its presupposed progenitors *N. sylvestris* and *N. tomentosiformis*. A number of derivatives were obtained from this specimen and a detailed study was made of their relationship to existing *N. tabacum* types. In addition, a *N. sylvestris-tomentosiformis* amphidiploid was developed from shoots which were produced in response to hormone treatments which formed callused tissue on the cut surface of actively growing F_1 *sylvestris-tomentosiformis* hybrids. The various segregants derived from these when crossed with standard strains also constituted an interesting phase of these investigations. In brief, the factor relationships, as determined for some of the more important characters, may be indicated as follows: black root-rot resistances $R_1\ R_1\ R_2\ R_2$; intermediate resistance $R_1\ R_1\ r_2\ r_2$ or $r_1\ r_1\ R_2\ R_2$; susceptibility $r_1\ r_1\ r_2\ r_2$; mosaic resistance $s_1\ s_1\ s_2\ s_2$; chlorophyll-deficiency c c; lanceolate leaf-base Br Br Pt Pt; broad leaf-base Br Br pt pt; petiolate leaf-base br br Pt Pt; constricted leaf-base br br pt pt; carmine flower Wh Wh Pk Pk; pink flower Wh Wh pk pk; white flower wh wh Pk Pk or wh wh pk pk. It frequently happens also that black root-rot resistance is conditioned by a single pair of dominant factors. It also appears that brown root-rot resistance bears some relationship to black root-rot resistance. Since all strains so far tested that display resistance to black root-rot are susceptible to brown root-rot, and all those displaying susceptibility to black root-rot are resistant to brown root-rot, it is suggested that possibly the same factors are involved in each case.

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Earliness in maturity is conditioned by a series of quantitative factors.

The development of new strains through hybridization constitutes the major portion of the plant-breeding programme. The procedure adopted is determined by the objective and the segregation of the factors involved. No attempt, however, is made to improve the quality of the cured leaf of any of the standard varieties through hybridization. This is due to the fact that the finer elements of quality cannot be measured. They depend on flavour and aroma, the desirability of which cannot be determined by any mechanical device. Instead, four or five of the best varieties as established by the varietal tests are selected from each of the types, flue-cured, burley, dark, and cigar, and a definite programme is built around each variety. Need of brevity prohibits a detailed discussion, but a reference to the work on diseases, since it constitutes one of the major problems, should suffice to indicate the procedure. In the development of resistance to mosaic each of the five flue-cured varieties, for instance, is crossed with Ambalema, the mosaic-resistant parent. As previously stated, mosaic resistance is conditioned by two pairs of recessive factors. It is, therefore, necessary to inoculate with the mosaic virus all plants in each of the F_2-populations to determine the resistant segregants. Two or three of the resistant selections are selfed and also back-crossed to the desired flue-cured parent. The progenies from the selfed plant should all be resistant. If by chance they are not it becomes necessary to discard all seed from the back cross to this selection. The F_2 of the back-cross is subjected to the same treatment as the original F_2-population, and this process is continued for several generations until the resistant type of the desired parent is established. Similar programmes are under way for the varieties of the other types. In addition, extensive work is being done, in somewhat the same way, in an attempt to establish a large number of root-rot resistant strains, earliness in maturity, chlorophyll-deficiencies, and differences in leaf-shapes. Once the strains have been established they are sent out to the most appropriate experimental station for inclusion in a varietal test before being released to the grower in that particular district.

Standardization and classification are conducted on all strains in which the slightest variability has been observed. This condition is frequently encountered among cultures the seed of which was imported from foreign countries or received from private sources. No seed is permitted to leave the Division's office until stability in all the expressed features of the strain has been established. All new strains are placed in such plots before being put into the regular varietal test-plots, and they remain there until the various characters are fixed. The diversity of forms derived from one original population is effectively displayed in plots of this nature at the Dominion Experimental Station at Harrow, Ontario. It is in plots such as these that the most detailed notes respecting all varieties are taken. These notes all appertain to field-growth characteristics and include measurements on the height of the plants at various stages throughout the season, shape, size, and number of leaves, relative maturity, &c. One of the most outstanding contributions

of this procedure has been the development of Harrow Velvet, the most popular burley variety grown in Canada at the present time. In addition, certain flue-cured strains such as White Mammoth 61, Yellow Mammoth 58, Bonanza 68, and Duquesne 72 constitute other outstanding derivatives.

The varietal testing of new introductions includes only those which have advanced from the standardization and classification plots by virtue of their greater promise. They may owe their origin to local hybridization and selection or to importation from another tobacco-producing country. All new strains are tested against the best standard strain of the same type whose history and record were previously established. The cigar tests are conducted at the Dominion Experimental Stations located in the cigar-producing areas, and flue-cured strains are tested at the stations located in the area where flue-cured tobacco is produced. All the strains of the other types are similarly tested. In such tests yield and quality data are of prime importance, and every effort is made to see that all features indicative of quality are recorded accurately. In this connexion it may be stated that most of the better strains of the various types grown in Canada were developed by the Dominion Experimental Farms Service.

Research Effective

That the research work referred to above has been of some value to the industry is recognized by a brief review of the recent progress and economic position of the industry. With the introduction of more suitable varieties and improved farm practice based on experimental results, the quality of Canadian tobacco has been improved greatly during the past decade. Its high quality is now recognized not only in Canada but also in other countries. The use of Canadian tobacco in the manufacture of cigarettes, for instance, has advanced from 41·1 per cent. in 1930 to 88·3 per cent. in 1940. Similar increased use of domestic leaf in the manufacture of other tobacco products such as cigars, cut tobacco, and snuff has been effected. During the period, imported tobacco used in manufacture has accordingly decreased from 17 million to $4\frac{1}{2}$ million pounds, so that the percentage of imported tobacco used in the manufacture of all tobacco products has decreased from 46 per cent. to 9·6 per cent. Exports of leaf-tobacco have expanded from 6·7 million pounds in 1931 to 32·2 million pounds in 1939. In addition, during the ten-year period the annual *per capita* consumption of cigarettes has increased from 437 to 663 and cut tobacco from 1·59 to 2·23 lb.

It is not expected, however, that the economic progress during the next decade will be as phenomenal as that witnessed by the past ten or fifteen years. Nevertheless, Canada is prepared to double its maximum record production on short notice should it be demanded by market requirements.

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